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ORIGINAL ARTICLE

The effect of interdisciplinary teamwork on creativity through knowledge heterogeneity and synthesis in a technological domain

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ABSTRACT

In this paper, creativity of students in interdisciplinary (ID) teams during the divergent (brainstorming and idea generation) phase is studied. The background of the students varied between undergraduate and graduate studies, and the creativity was stimulated amidst a discussion involving innovative solutions for the future of existing technologies In addition, the effect of knowledge -heterogeneity and -synthesis is discussed. The study is conducted via a survey among the participants of the Delft/CERN IdeaSquare e-Summer School 2020, held online from June 2020 to August 2020. The surveyed cohort was asked about the quantity of the generated ideas and their agreement to different statements, regarding size of the knowledge gap, effort to communicate and provide feedback, enjoyment, productivity and composition of their teams. The majority of the responding students believed they would produce the same or more ideas in ID teams, compared to that during monodisciplinary team work. We compared the agreement (between 0% and 100%) with the number of individual ideas and found a correlation for each mentioned category. This study is a first step to show that ID teams in a technological setting can be more productive. Further research should be done to repeat the experiment in a more controlled environment and solidify the hypothesis.

Keywords: Interdisciplinary; team; creativity; team work; divergent phase; brainstorming; ideas.

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INTRODUCTION

Scholars have acknowledged the significance of innovation in business (Alves et al. 2007; Moirano et al. 2020; Tang & Werner 2017; Moirano et al. 2020). Organizations undertake innovation efforts to create technological advancements to achieve a competitive advantage with lower production costs or new and exciting business opportunities. Edmondson & Harvey (2018) describe interdisciplinary (ID) teamwork as a highly effective strategy to foster innovation. Likewise, Parjanen & Hyppiä (2019) stress that interdisciplinarity is a basic requirement for collective creativity. *Interdisciplinary* teamwork is an intricate process in which different functional skills are combined to realize a common purpose. Bassett-Jones (2005) have highlighted that functional diversity is a prerequisite for creativity and complex problem-solving.

However, others have also shown that ID teams are likely to encounter difficulties with communication, which results in misunderstandings and conflict, thereby hindering the generation of creative ideas (Dougherty (1992); Pennington (2016)). Pennington (2016) defined the concept of *knowledge heterogeneity* as the degree of difference between the knowledge of all individuals in a team and the number of links between their knowledge bases. However, the author focused on "general" team performance, instead of creativity as an outcome. In addition, evidence that this theory also applies in a technological setting is missing, while Valente et al (2020) have discussed cooperation between technical and non-technical people as notoriously challenging. This was also suggested by Bella & Williamson (1977) for medical interdisciplinary teams.

The Delft/CERN IdeaSquare e-Summer School 2020, held online from June to August, presented a unique opportunity to extend the findings on knowledge heterogeneity and interdisciplinarity to a technological application domain. During the summer school, students from Honors Programs across three different universities, from both undergraduate and graduate studies, were selected to brainstorm, collaborate and engage in finding future solutions and applications of currently existing ATTRACT technologies, to combat a societal challenge of tomorrow. These students belonged from different study programs ranging from Engineering, Science to Business and Finance. At the end of the summer school, each team came up with an application of the technology assigned to them. One example of an idea generated was the detection of pollen in the air, and the communication of the data to the public through an app (like a weather application) using the technology assigned to the team. The prime and common goal of the interdisciplinary teams in this summer school was to come up with a novel application of the existing technology, which can be practically realized to address a societal challenge.

Creativity requires the originality as well as the effectiveness, as has been discussed by Runco & Garrett (2012). Innovation, on the other hand, can be a product, people or idea that can bring or follow novel methods as Merriam Webster defines it. Both these were tested amidst participants of the summer school. However, this paper discusses the creativity through measurement on both soft and hard data. The soft data involves feelings and emotions of the participant while the hard data provides for the number of ideas generated per person or team under the given settings. Only quantitative indicators were used for the measurement of creativity. All students belonged to Honors classes, but from different institutes and studies. This provided some homogeneity of knowledge but still a healthy variance.

This study adds to the existing literature by providing new insights into the effects of ID teams that include both students from a technical background and students from a background in business or social sciences. In this setting, teams are provided with a common purpose to find highly creative ideas for new applications of intricate technologies to address societal challenges. A brief guideline was introduced before the study to help students understand what kinds of experience they could consider when answering the survey. Subsequently, creative outcomes during the Summer School are compared with past personal experiences of subjects in mono-disciplinary (MD) teams, to answer the question:

How does working in ID teams, with differing levels of knowledge heterogeneity and -sharing, influence creativity in a technological application domain?

THEORETICAL BACKGROUND

Both MD and ID teamwork draw on knowledge from different disciplines. However, members of MD teams stay within the boundaries of their own discipline, whereas ID team members analyze, synthesize, and coordinate knowledge between their disciplines (Choi & Pak 2006). In relation to this, Körner (2010) discovered that ID teamwork outperforms MD teamwork in a medical setting. Tang & Werner (2017) extended these findings to an academic setting to investigate the effect of functional and cultural diversity on creativity and innovation. They found that the synthesis of different disciplines with a common goal generates a more valuable outcome than the sum of the individual disciplines. This study follows the existing literature to favor ID over MD and highlights the importance of knowledge synthesis.

Some studies, like that of Tang & Werner (2017), found evidence that working in ID teams has a positive effect on creativity or innovation. To outline the concept of *creativity* in more detail, it may refer to an idea, person, process, product, or environment (Isaksen et al. 2001). King and Anderson (1995) defined the fundamental meaning of creativity as a novelty and perceived benefit. Alves et al. (2007) contrast the meaning of creativity with innovation. They stated that creativity is associated with idea generation- it is the ability to come up with a high quantity and/or quality of ideas. On the other hand, innovation implies the transformation of ideas into new products or services. This distinction is important because the common goal of the ID teams in this study only permits the test of creativity. Regarding the factors that support creativity, the study of Linsey et al. (2008) suggests that individuals gain a significant number of new ideas from other team members. Furthermore, team members tend to think of more ideas if they view a subset of others' ideas.

Burnet et al. (2017) undertook a study that applies physical science and CERN technology to the problem of radiotherapy toxicity in ID teams. They found that an effective *exchange of knowledge* is essential. Dougherty (1992) tested ID teamwork in a business setting and showed that functional diversity can also lead to *communication barriers* when team members do not synthesize expertise. Pennington (2016) conducted a systematic literature review on the barrier of integrating knowledge to find underlying explanations. Pennington's results highlighted the benefits of synthesizing knowledge to reduce knowledge heterogeneity. Existing studies thus explained the relation between knowledge synthesis and communication barriers. However, these studies focus on the outcome of "general" team performance and communication, whereas this paper studies only creativity.

Newell (2007) further elaborated how knowledge heterogeneity comes from each team member's tacit *assumptions* based on their professional backgrounds. If these assumptions or ideas are in conflict with that of the others, team members become aware and have to find a common terminology, subsequently improving team effectiveness. The results of a study by Wenger (2000) support these findings and state that team performance is greatest when team members share knowledge, but still, embrace *conflict*. The work of Newell (2007) and Wenger (2000) thus highlighted the importance of assumptions and conflict in ID teamwork, although they excluded the link to knowledge heterogeneity and creativity.

To sum up, the existing literature stresses the importance of ID teams on creativity and the positive effect of knowledge synthesis. Studies find clear evidence for the importance of conflict to reduce communication barriers and show that knowledge synthesis reduces the negative effect of knowledge heterogeneity on team performance. However, a study on the relationship between knowledge heterogeneity in ID teams and creativity seem missing. Additionally, studies on ID teams and creativity are conducted in a medical, academic, or business setting. Evidence that this applies in technological settings is not found, while cooperation between technical and non-technical people is challenging (Valente et al, 2020) (Bella & Williamson, 1977). This paper adds to the literature by investigating teams that work creatively with technology. From this, the authors hypothesize:

Working in ID teams influences the outcome of idea generation (quantitative) positively in a technological domain.

Studies show that ID teamwork positively influences creativity in medical or academic settings (Burnet et al. 2017; Moirano et al. 2020; Edmondson & Harvey 2018; Parjanen & Hyppiä 2019). We extend these findings to a technical setting.

The existing literature on knowledge heterogeneity in ID teams indicates that the larger the difference in knowledge between two individuals, the higher is the communication barrier (Pennington 2016). This paper hypothesizes that this effect is opposite for creative outcomes because a study on creativity states that team members build on each other's ideas (Linsey et al. 2008). The more knowledge heterogeneity in the team, the more is the prevalence of the different ideas and the more can the team members build on each other's different ideas. Therefore, the authors extend the hypothesis:

The effect is stronger for teams with increased knowledge heterogeneity.

Studies indicate that synthesizing knowledge results in better team performance through the creation of common terminology and a reduction of communication barriers (Newell 2007; Pennington 2016; Wenger 2000). Therefore, the authors also add:

The effect is stronger for teams that actively synthesize knowledge.

METHOD AND DATA

The aim of this study was to identify the difference between ID and MD teams in technological projects regarding the quantity of ideas generated during brainstorming sessions. Furthermore, the influence of knowledge heterogeneity and synthesis was to be investigated. The corona pandemic forced this study to be done fully online. The authors decided to run a survey on all students, with exceptions to the authors themselves (only Fig. 1 and supp. Fig. 1 include one entry coming from one of the authors. In the calculation of the correlations, this entry is left out.), and use the brainstorming sessions of the summer school together with students' MD experiences in the past to test the hypothesis. Instead of asking or observing the knowledge heterogeneity directly, the authors identified the knowledge gap and the effort to work together. This required the experiment to be split up in the following segments:

- quantify and qualify the outcome of a brainstorming session in an ID team and compare this to past MD experiences;
- identify the size of the knowledge gap in ID teams;
- identify the efforts to synthesise knowledge in ID teams.

The team size, preparation, duration, tools and context of the past MD brainstorming sessions may have differed from the compared ID brainstorm session. Research shows that participants continue the brainstorming phase longer if the team size is larger because they are able to produce more ideas in larger groups (Nijstad, Stroebe, Lodewijkx, 1999) (Linsey et al, 2008). The participants were not asked to consider sessions with only 4 participants. Personal experience of the authors show that most MD projects in schools and universities (scholar team efforts) use 4 or more students and therefore can be compared correctly. It will even strengthen the results if ID teams produce more ideas while the team size is smaller.

The survey

The questions were made to identify the listed aspects while maintaining anonymity. In order to determine the knowledge gap and the degree of knowledge synthesis, the participants were asked how much they agreed with different statements, regarding differences in knowledge, language barriers, communication etc. The survey consisted of the following questions (see supplementary for the full list and detailed wording):

- the team number;
- the number of individual and total ideas generated while brainstorming;
- difference with these numbers (personally and collectively) compared to past MD projects/experiences;
- whether the team was well-rounded;
- perceived knowledge gap in the teams;

- whether this knowledge gap hindered progress;
- the efforts to share knowledge and synthesise it;
- the efforts to provide and receive feedback;
- students' joy of working in an ID and MD project;
- problems encountered during the process (both personally and as observed in other team members) the possible reasonings behind them;

Data collection

The Delft/CERN Ideasquare e-Summer School 2020 brought together 5 ID teams of 4 BSc students to each tackle a societal problem using a single ATTRACT technology. The ID teams were formed to reflect the variety of student backgrounds, which involved economic, environmental, computer, social and natural sciences. During the Summer School, multiple exercises were done to boost creativity. Each team then performed a single brainstorm session for their own project via the Zoom online meeting platform, for a set time. The survey was sent out directly after each team chose their best idea, a week after the brainstorm sessions took place. Only 10 students, at least 2 per team, completed the survey even though they were reminded and requested to do so twice. This is partially explained by the fact that the authors themselves could not contribute and one student abandoned the project early, leaving only 15 students to be surveyed . For each team, the average agreement per question, a percentages between 0% (*strongly disagree*) and 100% (*strongly agree*), was calculated and grouped in the following topics (how each question was divided is explained in the supp. data):

- size of knowledge gap
- active communication
- enjoyment in ID compared to MD teams
- feedback
- productivity and learning
- well-roundedness of the teams

The average percentage for each topic was used as a measure of the topic itself (e.g. if the knowledge gap was 0%, it would be none existed). Then, the agreement percentage was set out against the number of generated ideas to find the correlations stated in this paper's additional hypotheses. In the next section these results are presented.

RESULTS

The results consist of two parts. In the first part, the quantity of the students' ideas, generated during both ID and MD brainstorming sessions, are presented. In the second part, the authors identify the knowledge gap and -synthesis and relate this to the number of ideas generated.

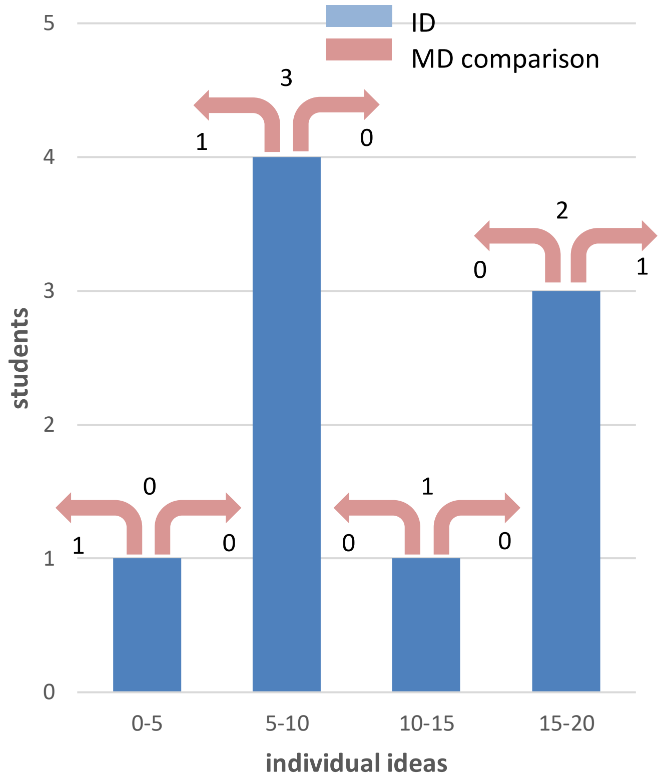

Fig.1. A histogram of the number of individual ideas generated during this ID project in blue. The red arrows show how many students would produce more, equal or less ideas in a MD setting.

Quantity of ideas in ID and MD teams

The amount of individual generated ideas spanned between 0 and 20: 10% said 0-5, 40% said 5-10, 10% said 10-15 and 30% said 15-20. These numbers are shown in Fig. 1 and compared with the MD case. The red arrows indicate how many students said they would produce fewer (left arrow), the same (in between) or more (right arrow) ideas in the MD case. For the collective case, all students said their team produced 15 or more ideas, with 70% stating they found more than 20. Supp. Fig. 1 compares these numbers with the MD case similar to

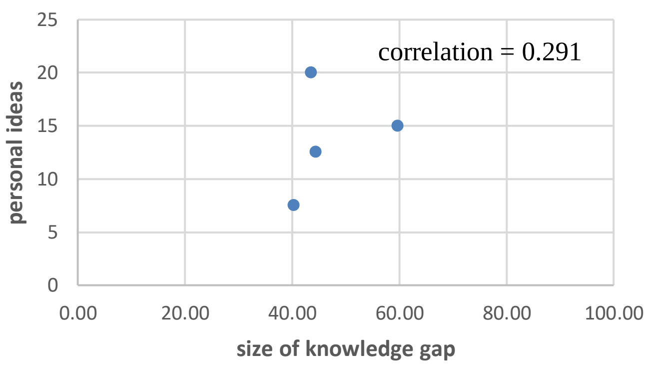

Fig.2. Using the agreement on the knowledge gap as a measure of the size of the knowledge gap, it is plotted against the number of individual ideas averaged per team. Each dot is a single team.

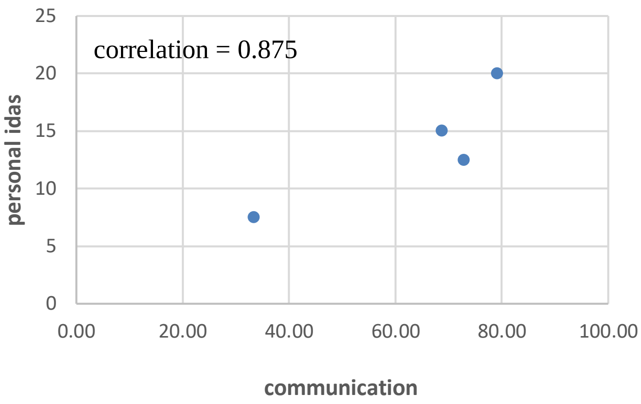

Fig. 3. Using the agreement on questions regarding communication as a measure of the effort to communicate, it is plotted against the number of individual ideas averaged per team. Each dot presents one team.

Fig. 1. Note that the replies from teammates may differ from one another and the individual ideas do not always add up to the given collective ideas. For both individual and collective, a majority stated they would produce the same number of ideas in a MD setting.
When summed up, only 1 student said they would produce more ideas in ID teams. When the question was asked explicitly at the end, 70% replied that ID teams produce more ideas, while the rest said both produce the same.

Correlation with knowledge gap

In addition, the students were asked how much they agreed on different statements. Per team, the average agreement was calculated, where 0% means they *strongly disagree* while 100% means they *strongly agree*. These percentages are shown in the supp. Tab. 2. per question. Then, the authors grouped the statements and calculated the average agreement per category, which can be viewed in supp. Tab 3. In order to find the correlations as hypothesised in the authors' hypothesis, the authors plotted the number of individual ideas, averaged over a team, against the size of the knowledge gap in Fig. 3. Here, the agreement on statements regarding the knowledge gap were used as a measure for the knowledge gap itself. Regarding knowledge synthesis, Fig. 4 does the same for communication. Tab. 1 shows the Pearson correlation factor for each of these graphs and for all the other categories. For the knowledge gap a moderate/low correlation was found (0.291). Regarding communication (0.88), feedback (0.82) and well-rounded teams (0.89), a very high correlation was found.

Tab. 1. The correlation between the listed topics, different aspects that may contribute to creativity, and the number of individual ideas averaged over a team.

Topic	Correlation factor
size of knowledge gap	0.291
active communication	0.875
feedback	0.824
enjoyment in ID compared to MD	0.894
productivity and learning	0.601
well-rounded teams	0.891

DISCUSSION AND CONCLUSIONS

In this study, the creativity of students in ID technological projects was compared to past MD team experiences. In particular, students from the Delft/CERN Ideasquare e-Summer School 2020 were asked to give the number of ideas they generated and give an overview of their experiences during the divergent phase of their project. Moreover, the number of individual ideas generated in each team was compared to the knowledge gap within that team, efforts to communicate and other topics.

Students came up with a great number of ideas, both individually and as a collective. Comparing this to MD, a majority stated they would produce the same number of ideas or less. However, when the question which team produces more ideas was asked explicitly, the percentages of ID-respondents was much higher, and none said MD produce more ideas.

The quantitate difference in idea generation for both types of projects might be caused by their own goals. MD teams often work towards a specific goal (the application for the technology may even be predetermined), whereas ID teams are often assigned to much broader (breakthrough innovative) projects that need extended brainstorming sessions.

Furthermore, this research found high correlation factors when comparing the number of individual ideas to the effort to communicate (0.84) or provide feedback (0.87). This was lower for the knowledge gap, at 0.44. This is expected because a large knowledge gap requires more communication and understanding. Therefore, this paper can conclude that a large knowledge gap in itself does not lead to more creativity automatically. This is in line with (Burnet et al, 2017) and (Pennington, 2016). Moreover, the discussed correlations may not be independent, leading to a more complex picture than anticipated.

In hindsight, the survey should have been setup more carefully. Instructions lack regarding which MD experiences were to be compared. To compensate for this, this research made the assumption that the MD projects used 4 or more students and involved some technological goal within the students' expertise. Only 6 out of 10 students were beta orientated, so the latter assumption is dubious.

Optimally, the authors would invite students from different backgrounds, create teams and put the teams through multiple brainstorming sessions. To find any difference between ID and MD, the authors would repeat the sessions at least twice: one with MD teams and one with ID teams. The data would then be collected by hand or by observation and the participants would fill in a survey reflecting on those sessions. An in-person experiment could provide a larger dataset and more control over the brainstorming sessions. This could be done as a follow up study.

Overall, this study found that ID teams are as creative or more compared to MD teams in a technical setting although the difference may be small. To discover the effect of knowledge heterogeneity and knowledge synthesis on idea generation, the authors combined the experiences of the students with the amount of ideas they generated. Strong or moderate correlations were found between different aspects of working in ID teams, including the efforts to communicate and provide feedback, and the number of individual ideas. Follow-up research can be done to confirm these results and conduct the ideal experiment as described above.

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SUPPLEMENTARY MATERIALS

In the supplementary document the full survey is listed, as well as the division of the statements in the different topics. The histogram for the collective case is also presented. Lastly, the ungrouped and grouped agreement percentages are tabulated as referenced.

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