CORRELATION BETWEEN TEAM COMPOSITION AND TEAM PERFORMANCE IN VIRTUAL STUDENT PRODUCT DEVELOPMENT TEAMS

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Abstract

This paper is presenting an experiment which was performed to investigate the correlation between team composition and team performance in specific case of virtual student teams working on industrial assignments of new product development. The experiment is based on Belbin's team role framework with the hypothesis that balanced teams perform better than unbalanced teams. The paper also briefly introduces the EGPR course and student virtual teams, which served as the objects of the experiment. The experimental results show no correlation between team composition and team performance, which is in line with some other studies. Many researchers argue that team composition indices used in various studies might not be appropriately defined. EGPR course has some specifics which have to be taken into account when evaluating this study: it has student product development teams, although the EGPR projects are characterized by high level of authenticity, the teams are partially virtual and partially co-located, international and coached by experienced university staff. All these characteristics might influence the correlation.

Keywords: Design education, Design learning, Collaborative design, Belbin's framework, Team performance

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1 INTRODUCTION

The development of innovative and competitive products and mastery of information and communication technologies (ICT) are crucial for any company's long-term success in the global information society and the global market. It is vital to understand that winning in a competitive environment is based on the combination of low-cost, innovative, high-quality products and responsiveness to market demand (Allan and Chisholm 2008, Prusak 1998). It also needs to be emphasized that in a world that can only survive through global collaboration, international cooperation is indispensable (Jansen 2002).

These facts force companies into forming of cross-functional teams that lead to functional merging of geographically, organizationally and culturally dispersed human resources, including product developers. In view of many companies, developing global products necessitated drawing on the local expertise of individuals, who reside in the countries for whom new products were being developed (McDonough et al. 2001). Product development is a demanding and complex activity as it is, and the ever-changing business environment additionally increases its level of difficulty, primarily by functional association of geographically dispersed human resources (Žavbi and Tavčar 2005). An organisational unit potentially capable to perform product development within actual business environment is a virtual team. A virtual team is a group of geographically dispersed people who interact through interdependent tasks guided by a common purpose with the support of information and communication technology (Boudreau, et al. 1998, Fain et al. 2016).

According to RW3 Culture Wizard's 2016 survey, e.g. 85% of respondents work on virtual teams, 63% work on one to three teams, but only 22% of respondents received training to increase their productivity on virtual teams (Solomon 2016).

From the above introduction it is evident that (virtual) teamwork is one of the key characteristics of modern product development (among other types of international cooperation). Working in teams is also recognized as one of the key professional competencies (sometimes called soft skills or transferable skills) by many authors, e.g. (Atman, et al. 2010, Dym, et al. 2005, Lucena, et al. 2008).

The purpose of the paper is to present an experiment and its results regarding team composition and correlation to team performance. In the section 2 Belbin's team role framework is presented, followed by some results of relations between team composition and team performance found by other researchers. The section also proposes hypothesis tested by the experiment. The method applied to conduct the experiment is explained in the section 3: it briefly introduces the EGPR course and product development student partially virtual teams, which served as the objects of the experiment. It also presents tasks and evaluation of the team results that were used as measure of team performance. The experimental results are presented in section 4 and discussed in section 5, together with a conclusion.

2 THEORETICAL UNDERPINNINGS

It is believed that team composition is the key influential factor of team performance. Optimal blend of team members' competencies (i.e., the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skilfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations, such as professional work, civic engagement, and personal life (Passow 2007) facilitates teamwork and enables better performance than less optimal composition (Mathieu, et al. 2015).

In order to evaluate influence of the team composition it needs to be defined somehow. Many authors use attributes such as functional specialties, knowledge, age, tenure, personality, gender, size of a team, teamwork orientations etc. (Ancona and Caldwell 1992, Mathieu, et al. 2015, Belbin 1993) to index a team composition. These attributes motivate and enable team members to occupy different team roles (Mathieu, et al. 2015, Stewart et al. 2005). According to (Belbin 1981), the term "team role" describes a pattern of behaviour characteristic of the way in which one team member interacts with another where his performance serves to facilitate the progress of the team as a whole.

Team roles are mainly considered a critical part of effective teaming (Ancona and Caldwell 1992, Belbin 1993).

Further on, the pattern of role balance has crucial effect on the team output. Types of behaviours people can exert are infinite, but the set of behaviours that contribute to team performance are finite (Belbin 1993).

2.1 Team roles framework

Belbin developed one of the most widely used team roles framework (Belbin 1981, Belbin 1993). In this framework eight team roles are defined (Belbin 1981, Belbin 1993, Fraser and Neville 1993):

- *Shaper (SH)* - highly motivated person with a lot of nervous energy and a great need for achievement. Often he/she seems to be aggressive extrovert with strong drive. Shapers like to challenge, to lead and to push others into action - and to win. If obstacles arise, they will find a way round - but can be headstrong and emotional in response to any form of disappointment or frustration. Shapers can handle and even thrive on confrontation. Allowable weaknesses: prone to provocation, irritation and impatience, and a tendency to offend others.
- *Plant (PL)* - is innovator and inventor and can be highly creative. He/she provides the seeds and ideas from which major developments spring. Usually plants prefer to operate by themselves at some distance from the other members of the team, using their imagination and often working in an unorthodox way. They tend to be introverted and react strongly to criticism and praise. Their ideas may often be radical and may lack practical constraint. They are independent, clever and original and may be weak in communicating with other people on a different wave-length. Allowable weaknesses: up in the clouds, inclined to disregard practical details or protocol.
- *Coordinator (CO)* - is useful person to have in charge of a team with diverse skills and personal characteristics. Coordinators perform better in dealing with colleagues of near or equal rank than in directing junior subordinates. Their motto might well be "consultation with control" and they usually believe in tackling problems calmly. In some organisations, co-ordinators are inclined to clash with shapers due to their contrasting management styles. Allowable weaknesses: No pretensions as regards intellectual or creative ability.
- *Monitor evaluator (ME)* - is serious-minded, prudent individual with a built-in immunity from being over-enthusiastic. Monitor evaluators are slow deciders who prefer to think things over - usually with a high critical thinking ability. Good Monitor evaluators have a capacity for shrewd judgements that take all factors into account and seldom give bad advice. Allowable weaknesses: lack of inspiration or the ability to motivate others.
- *Resource investigator (RI)* - is good communicator both inside and outside the organisation. Resource investigators are natural negotiators, adept at exploring new opportunities and developing contacts. Although not necessarily a great source of original ideas, they are quick to pick up other people's ideas and build on them. They are skilled at finding out what is available and what can be done, and usually get a warm welcome because of their outgoing nature. Resource investigators have relaxed personalities with a strong inquisitive sense and a readiness to see the possibilities of anything new. However, unless they remain stimulated by others, their enthusiasm rapidly fades. Allowable weaknesses: liable to lose interest once the initial fascination has passed.
- *Implementer (IMP)* - is well organised, enjoys routine, and has a practical common-sense and self-discipline. Implementers favour hard work and tackle problems in a systematic fashion. On a wider front they hold unswerving loyalty to the organisation and are less concerned with the pursuit of self-interest. However, Implementers may find difficulty in coping with new situations. Allowable weaknesses: lack of flexibility, resistance to unproven ideas.
- *Team worker (TM)* - is the most supportive member of a team. Team workers are mild, sociable and concerned about others with a great capacity for flexibility and adapting to different situations and people. They are perceptive, diplomatic, good listeners and are generally popular members of a group. They cope less well with pressure or situations involving the need for confrontation. Allowable weaknesses: indecision at moments of crisis and some failure to provide a clear lead to others.
- *Completer-finisher (CF)* - has a great capacity for follow-through and attention to detail, and seldom starts what he/she cannot finish. Completers-finishers are motivated by internal anxiety, although outwardly they may appear unruffled. Typically, they are introverts who don't need much external stimulus or incentive. Completer-finishers dislike carelessness and are intolerant of those with a casual disposition. Reluctant to delegate, they prefer to tackle all tasks themselves. Allowable weaknesses: a tendency to worry about small things and a reluctance to "let go".

These roles are grouped into three clusters:

- *Action oriented roles* (implementer, completer/finisher, shaper).
- *People oriented roles* (coordinator, team worker, resource investigator).

- *Thinking/problem solving oriented roles* (monitor/evaluator, plant).

Later Belbin added a ninth role as a result of his post-experimental industrial work (Belbin 1993, Fraser and Neville 1993):

- *Specialist* - is dedicated individual who prides himself/herself on acquiring technical skills and specialist knowledge. Specialists' priorities are to maintain professional standards and advance their own subject. While they show great pride in their own work, they usually lack interest in other people's work, and even in other people themselves. Eventually, the specialist becomes the expert by sheer commitment along a narrow front. Few possess the single-mindedness, dedication and aptitude to become a first-class specialist. Allowable weaknesses: contribute only on a narrow front.

2.2 Belbin's self-perception inventory

Belbin developed a questionnaire (a self-perception inventory-SPI), a simple instrument of assessing individuals' (i.e. (future) team members') team roles (Belbin 1981). The SPI consists of 7 sections and each section of 8 statements. An individual has to distribute 10 points among several statements which best describe an individual's behaviour: he/she might even distribute 10 points among all the statements or only to a single one. Table 1 shows an example of one of seven sections.

Table 1. A section of a SPI with distributed 10 points (Fraser and Neville 1993)

If I am suddenly given a difficult task with limited time and unfamiliar people:		
Tick		Points
	I often find my imagination frustrated by working in a group.	
	I find my personal skill particularly appropriate in achieving agreement.	
	My feelings seldom interfere with my judgement.	
x	I strive to build up an effective structure.	7
x	I can work with people who vary widely in their personal qualities and outlook.	3
	I feel it is sometimes worth incurring some temporary unpopularity if one is to succeed in getting one's views across in a group.	
	I usually know someone whose specialist knowledge is particularly apt.	
	I seem to develop a natural sense of urgency.	

The allocated points from all the sections of the SPI have to be transferred to a dedicated scoring key for SPI. The highest total indicates how best an individual can make his/her mark in a team (i.e. his/her primary role). The next highest total indicates his/her secondary (i.e. back-up) team role. The two lowest totals in team-role imply possible areas of weakness (Belbin 1981).

2.3 Team role balance

A team needs to be well-balanced, meaning that all the relevant team roles are well represented (Belbin 1993, Partington and Harris 1999): in (perfectly) balanced team each role has to be represented in at least one team member's profile at a high (i.e. 66-85%) or very high level (85-100%). The percentiles are based on the scores of SPIs of student team members (see section 3.1). On the other hand, (perfectly) unbalanced team would have team members with the same role preference (Meslec and Curşeu 2015).

A lot of studies consider relations between team performance and team balance, but the results are mixed (Batenburg et al. 2013). Some results supported positive correlation (e.g. (Belbin 1993)), some of them showed partial support (e.g. (Meslec and Curşeu 2015, Park and Bang 2002, Senior 1997)) and some of them showed no significant support (e.g. (Partington and Harris 1999, van der Water et al. 2008)). Nevertheless, the Belbin's theory is still regarded relevant to be further tested (Batenburg et al. 2013).

Since we have used teams in our EGPR course (see section 3) and observed variations in team performance, we have decided to use Belbin's SPI to test relation between team composition and team performance. According to the Belbin's theory and other authors' research (Meslec and Curşeu 2015, Partington and Harris 1999, Senior 1997, van der Water et al. 2008) we selected the following proposition:

- *P1: well-balanced teams will perform better than poor-balanced teams*.

3 METHOD

3.1 Sample and procedure

The research was performed during two projects of international design and development course called European Global Product Realisation - EGPR. EGPR is international course and partnership, currently consisted of four European Universities (University of Ljubljana, Faculty of Mechanical Engineering; City University of London; University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture; and Budapest University of Technology and Economics). It is tailored to teach engineering students professional knowledge and practical skills of new product development in geographically dispersed and virtual environment. Every year, the course is featuring a partner company which provides real industrial challenge to develop a product from idea to functional physical prototype in one semester timeframe. Enrolled students are distributed into international and interdisciplinary teams to support creativity and exchange of knowledge. The course also supports activities in a way to foster diversity of produced ideas and results rather than competition among teams.

Figure 1: Functional, full-scale prototypes of EGPR 2014 student project.

We analysed 68 participating students divided into 10 international virtual teams. Each team has at least 2 co-located students (i.e. from the same university), while other team members were each from different collaborating university and therefore geographically dispersed and collaborating virtually. The size of the teams varied from 5 to 8. The SPI (8 team roles) of all the team members was completed after the completion of the EGPR course, so the team members were not divided into teams based on their team role preferences. The ninth team role (i.e. specialist) was not included into the study because the students had no previous experience in product development nor they were experts in relevant domains - according to (Batenburg et al. 2013). The teams were supported by 5 experienced coaches (i.e. experienced academic staff involved in EGPR).

3.1.1 Project 1

In the second semester of study year 2013/2014 the project was organised in cooperation with Bosch Siemens small home appliances. The company wanted to explore new ideas for healthy meal preparation. Their goal was to combine the idea of healthy food with smart kitchen appliances which included also thermal treatment of food. The teams were free to explore various aspects of food preparation and played with different aspects of food processing for different target groups. The results

were demonstrated as 5 fully functional prototypes, which were built to demonstrate their main functions and design features. They are shown in Figure 1.

3.1.2 Project 2

In the second semester of study year 2015/2016 the project was organised in cooperation with Philips Lightning Ltd. The company is leading developer of consumer lightning solutions, trying to ease and enrich users' daily activities. As a part of this project, the company was interested in ideas to use lightning solutions to support and help life of the elderly. Through the cooperation during the course run, the company guided different teams into exploring different aspects of every-day life, of both - elderly and general population (Figure 2).

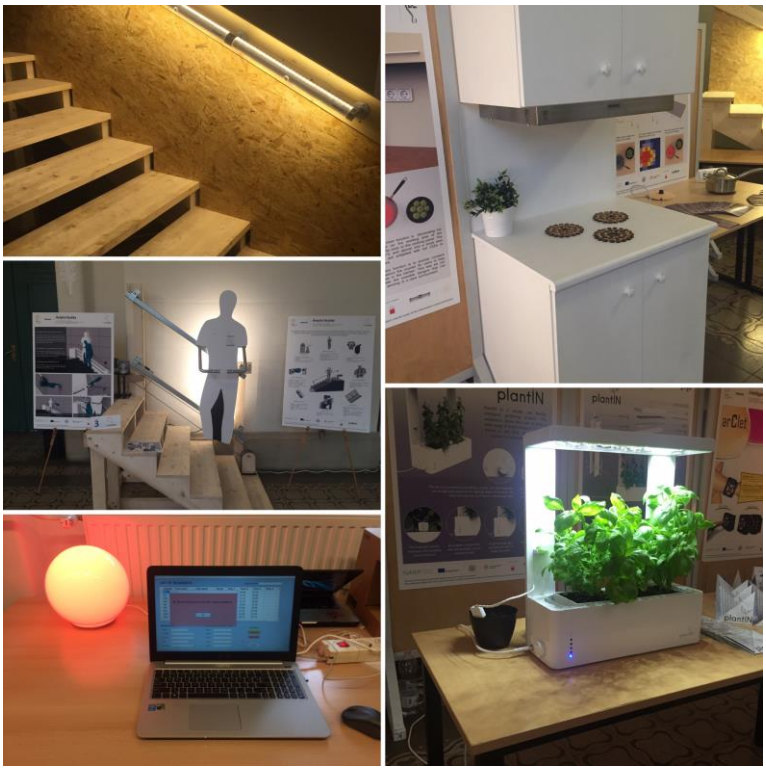

Figure 2: Functional, full-scale prototypes of EGPR 2016 student project.

3.2 Measures

3.2.1 Team balance indices

We used the balance indices TBI1, TBI2 and TBI3 as proposed by (Partington and Harris 1999) and also used by (Meslec and Curşeu 2015).

TBI1

TBI1 is based on the assumption that in a well-balanced team the aggregate points from all team members would be evenly spread across all eight roles (i.e. see Section 2.1). According to Belbin's SPI each team member contributes 70 points divided among the eight roles. In ideally balanced teams, the total score of all team members in each role divided by the number of team members would be 70/8=8.75 (Equations (1) and (2)).

$$\text{No. of roles} / (\Sigma\ (|\text{Role points average} - 70/\text{No. of roles}|) + \text{No. of roles}) * 100 \quad (1)$$

or:

$$8 / (\Sigma\ (|\text{Role points average} - 8.75|) + 8) * 100 \quad (2)$$

The higher the aggregate of absolute deviations from this ideal, the lower the team role balance. An example of the calculation of the TBI1 is presented in the Table 2.

*Table 2. Calculation of a TBI1 for one of the E-GPR teams (TBI1 = 8 / (23.50 + 8) * 100 = 25.4%).*

Team	Members									
Role	1	2	3	4	5	6	7	8	Role average	Deviation from 8.75
SH	6	0	4	9	7	0	6	1	4.13	4.63
CO	12	11	10	12	16	17	6	9	11.63	2.88
PL	0	7	11	0	0	7	2	10	4.63	4.13
RI	0	13	10	0	6	10	0	16	6.88	1.88
ME	22	19	2	19	3	2	11	0	9.75	1.00
IMP	19	0	9	10	9	5	14	6	9.00	0.25
TM	2	17	16	14	21	21	16	24	16.38	7.63
CF	9	3	8	6	8	8	15	4	7.63	1.13
									Sum dev.	23.50

TBI2

TBI2 is based on the assumption that a well-balanced team would have at least one member with high or very high scores in as many as possible of the eight team roles (Partington and Harris 1999). The roles were divided into four levels (i.e. low, average, high, very high) based on 33th, 66th and 85th percentiles of the ordered list of points for each role calculated from SPI of each team member; percentiles are used to measure and express the strength of an individual's team role level relative to that of the rest of all participants. (Belbin 1981, Meslec and Curşeu 2015, Partington and Harris 1999) (Table 3). If an individual's score achieves e.g. 9 points for the SH role then the role is of very high level overall.

Table 3. Norms for SPI of the E-GPR teams

Role	Low (0-33%)	Average (33-66%)	High (66-85%)	Very high (85-100%)
SH	0-1	2-5	6-8	9-16
CO	0-8	9-11	12-15	16-21
PL	0-3	4-6	7-9	10-15
RI	0-5	6-9	10-12	13-18
ME	0-1	2-8	9-16	17-22
IMP	0-3	4-9	10-13	14-23
TM	0-13	14-17	18-20	21-28
CF	0-5	6-8	9-14	15-29

By using the norms for SPI of the EGPR teams, each team was awarded 1 point for each role represented in a high (H)/very high (VH) level, and 2 points for each role unrepresented in high/very high level (Table 4). TBI2 is given by Equations (3) and (4):

$$TBI2 = \text{No. of roles} / \Sigma(\text{points awarded to represented or unrepresented role}) * 100 \quad (3)$$

or:

$$TBI2 = 8 / \Sigma(\text{points awarded to represented (1) or unrepresented (2) role}) * 100 \quad (4)$$

TBI3

According to (Belbin 1981) in a well-balanced team the roles should not be duplicated, therefore TBI3's calculation is based on the assumption that the team would have only one person scoring high or very high in as many as possible of the eight team roles (Partington and Harris 1999). By using the same norms for the SPI (Table 3), 1 point is given for each team member who has a role in high/very high level, and 2 points are awarded for each unrepresented role. The TBI3 is calculated as follows (Table 5):

$$TBI3 = \text{No. of roles} / \Sigma(\Sigma \text{ points awarded to each team member with a role) or unrepresented role)} * 100 \quad (5)$$

or

$$TBI3 = 8 / \Sigma\ (\Sigma \text{ points awarded to each team member with a role) or unrepresented role (2))} * 100 \quad (6)$$

*Table 4. Calculation of TBI2 for one of the E-GPR teams (TBI2 = 8 / 8 * 100 = 100%).*

Team	Members								
Role	1	2	3	4	5	6	7	8	
SH	H			VH	H				1
CO	H			H	VH	VH			1
PL		H	VH			H		VH	1
RI		VH	H			H		VH	1
ME	VH	VH		VH			H		1
IMP	VH			H			VH		1
TM					VH	VH		VH	1
CF	H						VH		1
									8

*Table 5. Calculation of TBI3 for one of the E-GPR teams (TBI3 = 8 / 27 * 100=29.6%).*

Team	Members								
Role	1	2	3	4	5	6	7	8	
SH	H			VH	H				3
CO	H			H	VH	VH			4
PL		H	VH			H		VH	4
RI		VH	H			H		VH	4
ME	VH	VH		VH			H		4
IMP	VH			H			VH		3
TM					VH	VH		VH	3
CF	H						VH		2
									27

3.2.2 Team performance

Team performance for the purpose of this experiment is defined as the team's output, i.e. a prototype developed during one-semester EGPR course. At the end of the course, when the prototypes were completed, coaches, company representatives and other staff officially performed user tests of the prototypes and evaluated the teams' outputs according to the predefined evaluation criteria. They awarded scores in form of percentages. The tests included weighted (k) evaluation of: (i) demonstration of the prototype and its functions (k=2); (ii) Level of completeness of the prototype (k=1); (iii) Innovativeness and 'globalness' of the prototype (k=2); (iv) Safety of the prototype (k=1); (v) Form (ergonomics, appearance, environmental) (k=2); (vi) Ease of fulfilling its main function (k=2); (vii) General ease of use and handling (k=1); (viii) User experience through the main function (k=2); (ix) Control support (remote control, app support, etc.) (k=2). The team performance score is the weighted sum of all above criteria results, adjusted to the scale from 0 to 100.

4 RESULTS

In order to find linear correlations between team performance, number of members, TBI1 and TBI3 we have conducted analysis of Pearson correlation coefficient the results of which are shown in Table. Balance index TBI2 was eliminated from this study because all the teams received maximum scores of 100%.

Significant correlation between team performance and TBI1 was not found $r(8) = 0.28$, $p = 0.429$. Team performance is not correlated with TBI3 $r(8) = -0.18$, $p = 0.623$. There is also no correlation between TBI1 and TBI3 $r(8) = -0.04$, $p = 0.912$. Number of team members is surprisingly not correlated with the performance $r(8) = -0.06$, $p = 0.875$. Among number of team members and TBI1 there is no correlation $r(8) = -0.06$, $p = 0.876$. Finally, number of team members and TBI3 is negatively correlated with $r(8) = -0.88$, $p = 0.001$.

Table 6. Bivariate correlations.

	Variable		
	1	2	3
Performance			
TBI1	0.28		
TBI3	-0.18	-0.04	
Number of team members	-0.06	-0.06	-0.88*

*p<0.001, Correlation is significant at the 0.01 level (2-tailed).

5 DISCUSSION AND CONCLUSION

The results based on the Belbin's SPI and team balance indices (i.e. TBI1, TBI3) indicate that there is no relationship between the team balance and the team performance. The absence of correlations is in line with the studies of Partington & Harris (1999) and partially Meslec & Curşeu (2015), whose results were based on the same definitions of the team balance indices. E.g. Batenburg et al. (2013) and van de Water et al. (2008) also found no relationship between team performance and team composition, but they used different team balance indicators. Some support for association of team balance with team performance was found by Senior (1997).

We found strong negative correlation between team size and TBI3, meaning that the larger the team the less balanced it is; there is more chance for team role duplication in larger teams. Such correlation was also found by Meslec & Curşeu (2015).

Senior (1997) addressed the issue on measure of team balance as also van de Water et al. (2008) did. E.g. TBI2 did not take into account the resonance if the same role is high scoring for several members of a team, and TBI3 was not realistic since most people have at least three so-called natural roles (i.e. roles with high/very high level) (van de Water et al., 2008). It is argued that existing team member balance measures did not appear to be good predictors of team balance and new ones should be constructed (Senior, 1997, van der Water et al. 2008).

Various studies have shown mixed results, but the results were based on different definitions of team balance measures. It seems rational first to unify measures of team balance which would allow more accurate comparisons of different studies.

EGPR course has some specifics which have to be taken into account when evaluating this study: it has student product development teams, although the EGPR projects are characterized by high level of authenticity, the teams are hybrid (partially virtual and partially co-located), international and coached by experienced university staff and the project tasks are not identical (although they belong to the domain of product development). International character of teams involves cultural differences that might influence correlation. Virtual collaboration is characterized by intense use of various means of electronic communication that requires appropriate communication skills in order to facilitate product development and working of a team; these facts might also have influence on correlation between team composition and team performance, because communication technologies could not fully replace standard face-to-face interaction. And last but not least, trust as one of the key dynamic processes within teams develops differently within a virtual team than in a co-located one, and it might also influence the correlation.

The study is based on the Belbin's team roles framework. It has been used to search for relation between student product development teams' composition and their performance. The latter is based on the evaluation of the prototypes developed within one semester EGPR courses. Further tests are necessary to reliably evaluate the existence of relation between product development team composition and team performance.

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