The Big Five and Visualisations of Team Work Activity

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Abstract. We have created a set of novel visualisations of group activity: they mirror activity of individuals and their interactions, based upon readily available authentic data. We evaluated these visualisations in the context of a semester long software development project course. We give a theoretical analysis of the design of our visualizations using the framework from the "Big 5" theory of team work as well as a qualitative study of the visualisations and the students' reflective reports. We conclude that these visualisations provide a powerful and valuable mirroring role with potential, when well used, to help groups learn to improve their effectiveness.

1 Introduction

Recent studies on computer-supported collaborative learning (CSCL) show that the expected beneficial outcomes of teamwork (such as high motivation, deep involvement in learning, and substantial knowledge gains) often do not materialise. An increasing number of studies and observations is reporting low participation rates, low levels of communication and collaboration (both in terms of quantity and quality of contributions), small knowledge gains, and little satisfaction with the group learning situation (e.g. [1], [2]). Kreijns, Kirschner and Jochems [3] have identified the tendency to assume that social interaction will occur automatically once the environments makes it possible, and the tendency to forget the social and psychological dimension of social interaction as two major pitfalls in designing and deploying collaborative learning systems.

We take the position that a group of students, in order to learn to work collaboratively, need to put effort not only in task-work, but also in *teamwork*. Teamwork can be defined as "…a set of interrelated thoughts, actions, and feelings of each team member that are needed to function as a team and that combine to facilitate coordinated, adaptive performance and task objectives resulting in value-added outcomes." ([4], p. 562). It is teamwork that ensures the success of teams at the workplace, and there is no reason to believe that this would be different for teams whose focus is on learning. The question of what processes and components comprise teamwork and how teamwork contributes to team effectiveness has received much attention in social psychology. A recent review of this body of research resulted in the identification of the "Big Five" components of teamwork [4]. The elements that make up teamwork, independent of the task a team has to perform, are [4]:

M. Ikeda, K. Ashley, and T.-W. Chan (Eds.): ITS 2006, LNCS 4053, pp. 197 – 206, 2006.

- Team Leadership: ability to direct and coordinate other team members' activities, assess team performance, assign tasks, develop team knowledge and skills, motivate team members, plan and organise, and establish a positive atmosphere.
- Mutual performance monitoring: ability to develop common understandings of the team environment and apply appropriate task strategies to accurately monitor teammate performance.
- Backup behavior: ability to anticipate other team members' needs through accurate knowledge about their responsibilities. Includes the ability to shift workload among members to achieve balance during high periods of workload or pressure.
- Adaptability: ability to adjust strategies based on information gathered from the environment through the use of backup behavior and reallocation of intra-team resources. Altering a course of action or team repertoire in response to changing conditions (internal or external).
- Team orientation: propensity to take others' behavior into account during group interaction and belief in importance of team goal over individual members' goals.

Teams that enact these five competencies will enjoy improved performance. However, in order to fully realise this performance improvement potential, research shows that three *coordinating mechanisms* need to be in place in addition [4]:

- Shared mental models: An organising knowledge structure of the relationships among the tasks the team is engaged in and how the team members will interact.
- Mutual trust: The shared belief that team members will perform their roles and protect the interests of their teammates.
- Closed-loop communication: The exchange of information between a sender and a receiver irrespective of the medium.

In our approach to support online (learning) teams, we trace students' interaction behavior along these dimensions and provide visualisations which are mirrored back to the groups. It is important to note that at this stage in time we are not attempting to provide groups with *feedback* in the strong sense that we could identify and visualise differences between optimal performance and a group's actual performance; rather, we *mirror* information pertaining to the components of teamwork for the groups (see also [5]). We believe that groups will profit from 'only' mirroring information, provided that this information speaks to the appropriate points. Building on the theoretically and empirically well grounded "Big Five" framework, we hope to have identified the appropriate points.

We have created a set of novel visualisations of group activity: they have been designed to mirror the activity of the individuals and their interactions, based upon readily available authentic data from the groups. We have evaluated these visualisations in the context of a semester long software development project course. The students worked in teams of 5 to 7 and were assessed on the demonstrated quality of the software product and the effectiveness of the software and group processes in achieving that product. Students were required to make use of the version control system Subversion (SVN, http://subversion.tigris.org/) to maintain the versions of their software and Trac (http://www.edgewall.com/trac/) to support group communication via a Wiki as well as a Ticket system which supports allocation of tasks and tracing them against milestones. Data from these was used to build visualisations of the activity of each person in each group.

The two main questions addressed in this paper are: How well do the visualisations capture information relevant in the context of the Big Five framework? Is there a relation between patterns identifiable through these visualisations and group performance outcomes? In the next section, the visualisations are introduced. Next, we analyse to what extent these visualisations allow one to assess the Big Five components. Finally, we describe relations between patterns as revealed by the visualisations and group performance. We conclude with a comparison to similar approaches.

2 Overview of Visualisations

Activity Radar. As shown in Figure 1, an Activity Radar (inspired by [6]) consists of a circle, representing the range of participation, and colored dots, each representing an entity for which we want to compare participation levels: often a dot is a team member but it could also be a classroom or a group. Each dot is placed on a radius (always the same one) and moves to the centre as the member's level of participation increases: a person whose dot is in the centre has the highest level of participation whilst a person whose dot is on the perimeter has the lowest level of participation. The inner, darker circle perimeter represents the average level of participation. The unit of the participation depends on the medium (which explains why we have three different graphs associated with the three media, mixing different units in a single graph would not be meaningful). For the SVN and for the Wiki media, the amount of participation is the number of added lines. For the Ticket medium, it is the number of ticket events performed by the member. The highest participation (the center) and the average (the perimeter of the dark inner circle) values can be defined separately, thus changing the scale. Therefore the scale can be relative to the group only or to the whole class.

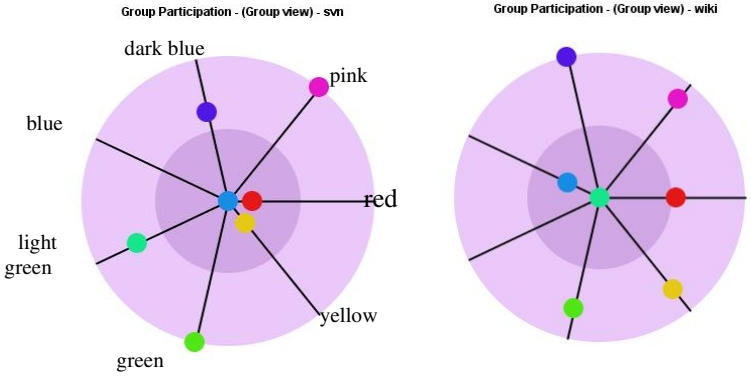

Fig. 1. Activity Radar for SVN and Wiki (colors will not show on black and white print)

For instance Figure 1 shows that the bulk of the SVN activity (on the left) is done by three students (blue, yellow and red). Whilst the blue dot was still very active on the Wiki medium (on the right), the red and yellow dots were much less engaged. The most active person on the Wiki (light green dot) was fairly inactive on the SVN.

Interaction Network. This representation is based on Social Network Analysis [7], which is concerned with capturing relationships and flows between entities. It assumes that these relationships reveal some important features of the group. The network is modeled as a unidirectional graph (although we have introduced some direction for one medium), consisting of a set of nodes and edges, where each node represents a user and an edge represents an interaction between the two corresponding users. In our context, we defined the notion of interaction between two members when they modify the same resource (in a specific interval of time or not). The width of the edge is proportional to the number of interactions between them.

Figure 2 shows an (ideal) case of a group where all team members interacted a lot with each other over the Wiki medium. In contrast, Figure 3 for SVN shows a different pattern of participation for a group where only three team members interacted.

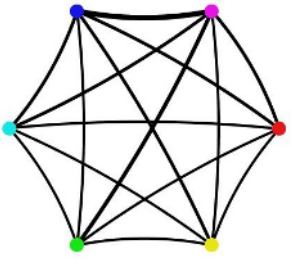

Fig. 2. Interaction Network for Wiki

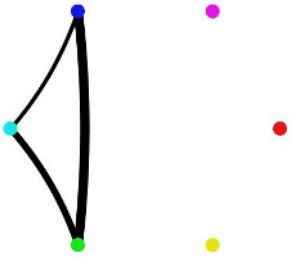

Fig. 3. Interaction Network for SVN

Wattle Tree. We have created the Wattle Tree[1] (see Figure 4), a novel graphical representation, where each user's activity is shown in a climbing vertical "tree" (timeline). The tree starts when the user first performs an action in any of the three media considered. The left axis indicates the day.

Wiki-related activity is represented by yellow "flowers", which, like the flowers on a wattle tree, look like yellow circles, appearing on the left of the trees. SVN-related activity is similarly represented, as (light and dark) orange flowers on the right of the tree. The size of the flower indicates the size of the contribution. Tickets-related actions are represented by leaves (lines in our current representation): a dark green (left) leaf indicates a ticket was open by the user whilst a light green (right) leaf indicates a closed ticket. The length of the left leaf is proportional to the time it remained opened. Those still open are shown at a standard, maximal size, as in the case of the bottom ones of Figure 4. A well-organised, efficient group should have many leaves, of small to medium length, on either side, with lots of activity (Wiki, SVN) in between. A small number of left leaves, especially if they are of maximal length, indicates that users work on very chunky and large tasks, and do not use the ticket system to good effect (eg. forget to close their tickets).

The group represented in Figure 4 shows that the team members used the Ticket system moderately well. Early in the project they used the Wiki often, whilst the SVN

[1] We use the analogy with the wattle tree (acacia), an Australian native tree with green leaves and grapes of round, fluffy yellow flowers.

activity kicked in a third of the way into the project. The overall activity is quite well spread in time, except for the clearly visible semester break. The distribution of workload shows a greater burden taken by the two left-most members but all members sustained a quite steady load. This is consistent with a normal, well involved group.

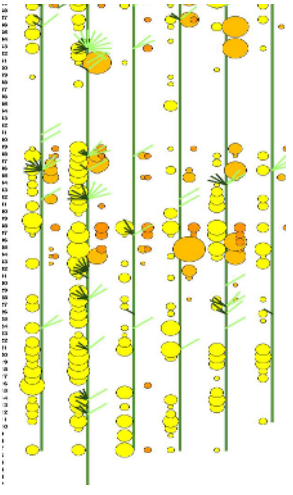

Fig. 4. Wattle Tree of a well-functioning group

3 How the Visualisations Can Relate to Each Big5 Factor

We seek here to investigate how the five important factors of successful team work and their respective behavioral makers can be assessed through our visualisations. We address each "Big 5" element in turn.

Team Leadership. This factor is easily observed in the Ticket actions: the team leader typically assigns many tickets (seen on AR/T[2]), to each team member (reflected on IN/T). S/he also interacts with all team members, through ticket activity and Wiki medium. We expect a good team leader to be close to the centre in AR/T within the average circle in AR/W, and to see thick connections from the leader to all other team members in the IN/T. The IN/W may also show important connections involving the team leader, but not exclusively. We also expect to see in the Wattle Tree a continuous activity from the team leader throughout the project, and a rise in ticket and Wiki activities before the deadlines.

Mutual Performance Monitoring. This factor can be partially assessed by the INs. A very low level of interactions between team members on all media may indicate that they do not monitor each other nor pick up mistakes and lapses. The Wattle Tree can also reveal important information, if we observe the time elapsed between team members' actions. Members of a monitoring team are quicker to respond to each other, and tickets do not remain open for a long time without reassignments.

[2] AR stands for Activity Radar, T for Ticket. Similarly we denote AR/W and AR/S, as well as IN/W, IN/T, IN/S for the three Interaction Networks.

Table 1. Team Leadership

Behavioral Markers	Activity Radar			Interaction Network			Wattle Tree[3]
	T	W	S	T	W	S	
Facilitate team problem solving	+	+		+	+		Continuity in time
Provide performance expectations and acceptable interaction patterns	+	+		+	+		Continuity in time
Synchronize and combine individual team member contributions	+	+		+	+		Continuity in time, esp. before deadlines
T = Ticket; W = Wiki; S = Subversion							

Table 2. Mutual performance monitoring

Behavioral Markers	Activity Radar			Interaction Network			Wattle Tree
	T	W	S	T	W	S	
Identifying mistakes and lapses in other team members' actions				+	+	+	Time elapsed between interactions, opening time of tickets.
T = Ticket; W = Wiki; S = Subversion							

Backup Behavior. A main aspect of backup behavior is the ability to shift workload amongst team members to achieve balance during periods of high workload and pressure. The IN/T would give an idea of how well tickets were distributed by the team leader. Activity Radars, on all media, are an indicator of how much each member participated on average. In particular the assignment and re-assignment of tickets gives a good indication of how tasks are distributed. However the most information is given by the Wattle Tree, as it shows, at any given time, the amount of activity for each team member. Whilst the actions captured may not precisely reflect the amount of work done by the participant (e.g. a small Wiki entry may in fact be the result of several hours work), there is a good indication of how workload is distributed. A week before an important deadline for instance, where there is usually a burst of activity, a team that practices backup behavior would shift tasks at that time to the less busy members. So we would expect to see an even workload during these periods of pressure, even if they are preceded by a short, uneven period.

Table 3. Backup behavior

Behavioral Markers	Activity Radar			Interaction Network			Wattle Tree
	T	W	S	T	W	S	
Recognition of workload distribution problem in the team.	+	+	+	+			Distribution of workload, re-balancing of workload
Shifting work to underutilised team members	+	+	+	+			
T = Ticket; W = Wiki; S = Subversion							

[3] In each table, we indicate with a '+' whether the visualisation addresses the marker. For the Wattle Tree, more complex, we give a textual clarification of what element addresses it.

Adaptability. This factor is difficult to assess as its absence does not imply that the team is not successful. For instance the task, team and resources may be problem-free, hence the team does not have the opportunity to show its adaptability. However if we know of a problem or a change then we can observe how the team reacted. One team, for instance, had an inactive "team leader" so one member informally took the lead and the team managed to complete the task. Whilst all the visualisations may show a problem (e.g. an inactive team member), the reaction of the team may not be always observable on the visualisations. When the time of these changes is known, then we can gain cues from the Wattle Tree since it is time-based. For example, we could see when the other team member took informal leadership of his team and how long it took the others to respond to his actions. Importantly, the team members, having deep knowledge of the dynamics and situation may recognise evidence of such shifts.

Table 4. Adaptability

Behavioral Markers	Activity Radar			Interaction Network			Wattle Tree
	T	W	S	T	W	S	
Identify cues of change, assign meaning to it, and develop a new plan to deal with it	+	+	+	+	+	+	See actions related to critical times. Time between actions
T = Ticket; W = Wiki; S = Subversion							

Team Orientation. The Wattle Tree provides a nice picture of the degree of involvement of each individual during periods of high pressure, such as the completion of a project milestone. AR and IN diagrams give an indication of how much the members participate overall, how much they interact and in which direction. Thick, even-colored links between team members show that they interact a lot, on average in a symmetric two-way fashion. Reassignment of tickets, tickets closed by other members are also evidence that other team members participate in a task.

Table 5. Team orientation

Behavioral Markers	Activity Radar			Interaction Network			Wattle Tree
	T	W	S	T	W	S	
Increased task involvement, information sharing, strategising, and goal setting	+	+	+	+	+	+	Coinciding actions in time
T = Ticket; W = Wiki; S = Subversion							

4 Relation to Group Performance

Here we only describe relationships between the visualisations and observed team performance, in particular relationships with the quality of outcomes (as reflected in grades for group management). Our first, and most important, source for gaining an understanding of student perceptions, was the final reports. Each group was required

to write a 1-2 pages reflective statement about its achievements, limitations and what had been learnt. In addition, students reported their contributions and made a reflective statement. Nine of the ten groups had access to the diagrams to use for their reports and six did so. The second main source of evidence was the information in the Subversion and Trac repositories: whenever we wished to understand more about a group, we could examine these in detail. Indeed, it is this huge collection of information that our visualisations are intended to summarise and overview. The following analysis is based around the elements of the Big Five model and reports our observations of the role of our visualisations, in relation to them.

Team Leadership

Facilitate team problem solving: In effective groups, the characteristic pattern of Wiki activity by the team leader appeared as many yellow flowers on their Wattle Tree. The Interaction Network clearly distinguished successful leaders because it showed that they interacted with all group members. For less successful groups, there are clear indications of problems: for example, a nominal group leader had absolutely no interactions with anyone on any medium. The Wattle Tree pattern of SVN submissions and Wiki activities for each member gave a gross indication of people performing assigned tasks. These were very valuable when combined with scrutiny of the details in the system.

Provide performance expectations and acceptable interaction patterns: In the final reports, it was striking that, in all 5 groups which referred to the diagrams, the team leader was one of the people who did so. They referred to them in relation to just these aspects of performance and interaction. One of them noted that they were unreliable in relation to one team member who did not make their own SVN submissions, but clearly showed that this aspect of the visualisations presented a very clear pattern.

Synchronise and combine individual team member contributions see and evaluate information that affects team functioning: For some groups, this was visible in the SVN interactions which seemed to occur when individual code was integrated. Our visualisations are complemented by the information that is presented by Trac/SVN on the history of each document.

Mutual Performance Monitoring

Identifying mistakes and lapses in other team members' actions: In the case of extreme social loafing, the Wattle Tree (and, to a lesser degree, the AR diagrams) made this very clear. The students tended to avoid criticising each other in their reports but two leaders pointed to the pattern in these diagrams as clear indicators of failure to contribute. The individuals involved made no comment on them (even though they should have read the whole report, including the leader's comments critical of them), perhaps because they had nothing to offer to refute this. In the case mentioned above where the group leader did the SVN commits for another person, that person mentioned this in their report and pointed to comments in the commit which indicated this. This case clearly shows that the displays made lapses evident.

Student reflections included several mistakes, such as doing the wrong job, but these were not visible in our displays. However, there were cases where students

reported a task being taken over because the person initially allocated it had problems and, somewhat surprisingly, this was reflected in a change in the Wattle Tree with a shift from SVN to Wiki activity.

Backup Behaviour
Recognition of a workload distribution problem in the team. The size of the flowers and their frequency are an indication of this. Although we were only able to make the diagrams available at the end of the course, they would have made an excellent basis for a group discussion earlier. For example, where a person was not active, this could be explored by the group.

Shifting work to underutilised members: As described above, this was sometimes visible in the change in pattern of SVN/Wiki activities of the individuals involved as well as interactions on the SVN for code from tasks taken over.

Adaptability
Identify cues of change, assign meaning to it, develop new plan to deal with it: This is similar to the issues of back up described above under backup.

Team Orientation
Increase task involvement, information sharing, strategising and goal setting. In successful groups, this seems to have been reflected in high Wiki activity early in the semester. It is also reflected in the Interaction Network diagrams with the most successful groups having quite rich interaction on the Wiki, with all members having some interactions with all others. There was also one group where the division of work meant that half the group had high interaction on the Wiki and the other half had high interaction on SVN. This matched their individual reflections.

5 Conclusion

We have presented our visualisations that externalise the long term activity of groups. The Activity Radar derives from Erickson [8], but we focus on asynchronous contributions over a long period rather than current chat actions. The Interaction Network is somewhat like Social Network Analysis diagrams. The most novel of our visualisations, the Wattle Tree, was inspired by Donath et al. [9] which summarises activity on a single medium by diffuse communities. The importance of this work is reflected in the large body of work in the CSCW community on various aspects of awareness [10], much of it informing the facilities available in Trac/SVN. We have not found any work that has captured the long term, high level, graphic summary of individual activity within teams. The Wattle Tree has proved particularly useful because it gives the right mix of detail and high level summary over a long period.

We have motivated our approach to visualising team interactions with the Big5 model of teamwork [4], and demonstrated that the visualisations can express various aspects of the components of teamwork. A qualitative analysis revealed a number of relations between patterns observable in the visualisations and team performance. As mentioned in the introduction, the visualisations do not communicate normative

information; they do not show how a group or a team member ought to perform. Current research fails to offer optimal values for the five components. It is also unlikely that a general optimal combination of values can be identified: they are affected by the situational demands, as well as the history of the group (e.g. how well the group members know each other) [8]. One way around this problem is to work purely inductively and base feedback on what worked for teams in similar situations [11]. This, however, requires analysis of a great number of similar situations. In our approach, the interpretations are left to the team members themselves or to those who are very familiar with the specifics of teams, such as their managers or, in instructional settings, tutors. This avoids the possibility of ill-founded feedback and advice; it can also be argued that leaving the normative decisions to groups themselves has positive motivational effects and has the potential to eventually lead to more stable and satisfied groups [12].

Acknowledgements. This work is funded by the Australian Research Council.

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