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An artificial intelligence tool for heterogeneous team formation in the classroom

Juan M. Alberola[a], Elena del Val[a,*], Victor Sanchez-Anguix[b], Alberto Palomares[a], Maria Dolores Teruel[a]

[a] Universitat Politècnica de València, Cami de Vera s/n, 46022 Valencia, Spain
[b] Department of Computing, Coventry University, Gulson Road, Coventry CV1 2JH, United Kingdom

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ABSTRACT

Nowadays, there is increasing interest in the development of teamwork skills in the educational context. This growing interest is motivated by its pedagogical effectiveness and the fact that, in labour contexts, enterprises organise their employees in teams to carry out complex projects. Despite its crucial importance in the classroom and industry, there is a lack of support for the team formation process. Not only do many factors influence team performance, but the problem becomes exponentially costly if teams are to be optimised. In this article, we propose a tool whose aim it is to cover such a gap. It combines artificial intelligence techniques such as coalition structure generation, Bayesian learning, and Belbin's role theory to facilitate the generation of working groups in an educational context. This tool improves current state of the art proposals in three ways: i) it takes into account the feedback of other teammates in order to establish the most predominant role of a student instead of self-perception questionnaires; ii) it handles uncertainty with regard to each student's predominant team role; iii) it is iterative since it considers information from several interactions in order to improve the estimation of role assignments. We tested the performance of the proposed tool in an experiment involving students that took part in three different team activities. The experiments suggest that the proposed tool is able to improve different teamwork aspects such as team dynamics and student satisfaction.

1. Introduction

In the last few years there has been increasing interest in teamwork skills in the area of Higher Education [1–5]. Many plans of study and faculties have included general teamwork competence as a part of their educational programs for undergraduate students. The reasons for this inclusion are well-grounded in its pedagogical effectiveness and our current industrial paradigm. Firstly, the area of collaborative learning, supported by computers, promotes collaboration and makes learning more effective [6]. Secondly, the industry has shifted from an individually oriented work environment towards a team-oriented workplace. Nowadays, teams are at the heart of a vast majority of modern companies [7–10]. Despite the often difficult decision-making tasks involving groups of individuals [11,12], teams have proven to have an inherent ability to solve the complex problems that are confronted in the current work environment.

Given this context, it is fairly reasonable for Higher Education institutions to place a special emphasis on teamwork skills as a part of every program's learning outcomes. Unfortunately, not every single team is successful in their goals, and many teams fail due to incorrect team dynamics, lack of communication, and interpersonal conflict among team members [12–14]. Even though some of the aforementioned problems can be alleviated with teamwork experience, these negative factors should be avoided whenever possible as they may generate resentment towards teamwork. Hence, identifying the patterns that drive successful teams and forming work teams according to these patterns become crucial tasks for every organisation. Classrooms are not immune to this issue (especially if students are to learn teamwork skills), and unnecessary problems may hinder this learning process.

One of the most important theories regarding successful team dynamics is Belbin's role taxonomy [15]. In this theory, Belbin identifies eight heterogeneous behavioural patterns that are present in many successful teams in the industry: *plant, resource investigator, coordinator, shaper, monitor evaluator, team worker, implementer, and finisher*. These behavioural patterns (or roles) should be played by the different team members in order to facilitate

* Corresponding author. Tel.: +34 963877350.
E-mail address: edelval@dsic.upv.es (E. del Val).

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successful teamwork. Belbin's taxonomy has given rise to a wide variety of studies showing the theory's strengths and weaknesses [16–20], it has been applied to a wide variety of domains [21–24].

As shown by several studies, the classroom environment may benefit from the application of Belbin's theory [25–29]. One of the reasons for this successful application in education is the identification of behavioural patterns that are present in many group dynamics. However, there are several problematic circumstances that should be addressed in order to apply Belbin's role taxonomy to the classroom. The first one is that Belbin's roles are classically identified by means of questionnaires (mainly self-perception questionnaires) that are filled out before working with others. However, self-perception results may differ from those patterns shown in a real team environment [30]. Therefore, we believe that a more effective role assignment could be achieved by considering both the information collected before working on a team and the feedback provided from peers after working on a team. The second one is that individuals are not purely described by just a static and strict role. Despite the fact that, due to the individual's personality, one may have a most predominant role, individuals show a rich variety of behavioural patterns depending on circumstances. Firstly, this makes the most prominent role of the individual uncertain, as the individual may show a range behaviours for different scenarios. Secondly, as the individual may show different behavioural patterns, the individual behaviour may be best described as a probability distribution over such patterns or roles that he/she plays. The third one is that even a small classroom with 30 students has $\binom{30}{5} = 142{,}506$ different teams of five individuals, and the total number of team configurations for the classroom explodes exponentially with this amount. Finding the best possible configuration poses a computationally expensive problem for it to be solved manually.

In this article, we present a computational tool that attempts to address the aforementioned problems. The tool is based on artificial intelligence (AI) and iterative interactions/feedback. The use of AI techniques allows us to address uncertainty and solve computationally expensive problems. More specifically, the tool makes use of Bayesian learning to tackle uncertainty with regard to students' prominent roles, and the problem of finding optimal teams is treated as a coalitional structure generation problem [31], which is solved by means of linear programming methods. Additionally, the proposed tool is iterative in nature: it proposes team configurations for class task assignments and then it gathers feedback from team members with respect to the roles portrayed by the other teammates. This information is later used to refine future team configurations proposed by the tool.

The remainder of this article is organised as follows. Section 2 describes the main features of the Belbin model. Section 3 presents how the tool would generally work and some implementation details. Section 4 presents an in-depth explanation of the mechanism used for team formation, which is at the core of our team formation tool. Section 5 analyses the impact of testing our proposal in a real educational environment. Section 6 shows the most relevant works in the literature with regard to team formation tools. Finally, Section 7 presents some concluding remarks and future work.

2. The Belbin theory

Prior to detailing how the proposed tool was implemented, we believe that it is important for the reader to be familiar with the Belbin theory since it is one of the fundamental pillars of our tool. The Belbin theory [15,32–34] provides a thorough of the influence of different types of roles in teamwork. A team role is defined as a behavioural pattern that facilitates the progress of the whole team. Assuming that there would probably be boundless behaviour patterns, Belbin states that the range of behaviours that really influence the performance of a team is limited. In Belbin's model, a role is defined by six factors: personality, mental ability, current values and motivation, field constraints, experience, and role learning [19]. Specifically, Belbin defines the following eight roles:

- **Plant/Creative**: is creative and imaginative. He/she generates ideas and solves difficult problems.
- **Resource investigator**: is outgoing and communicative. He/she explores opportunities and interacts with people outside the team.
- **Co-ordinator**: is mature and confident. He/she has a global view of the project and delegates effectively.
- **Shaper**: is challenging and dynamic. He/she has the drive and courage to overcome obstacles.
- **Monitor evaluator**: is sober, strategic, and discerning. He/she sees all options and judges accurately.
- **Teamworker**: is co-operative, perceptive, and diplomatic. He/she is able to listen and avert friction.
- **Implementer**: is practical, reliable, and efficient. He/she turns ideas into actions and organises work that needs to be done.
- **Completer finisher**: is painstaking, conscientious, and anxious. He/she searches out errors, polishes, and perfects them.

In later revisions of this theory, a ninth role of *specialist* was introduced for the case when technical expertise is necessary for the performance of certain tasks. Belbin's model has been associated to behaviours and performance. In line with other authors, Belbin has argued that the most successful teams are composed of a balanced combination of the above roles, ideally all of them. In contrast, teams composed of homogeneous roles tend to provide unsatisfactory results.

The Belbin model is traditionally operationalised through the Team Role Self-Perception Inventory, which allows each individual to discover his/her most prominent role based on his/her own judgment. The main disadvantage of this self-perception questionnaire is that individuals may have a preconceived image of themselves, which is diametrically different to the image that is reflected to others [30,35–37]. Complementary to this, an Observer Assessment Sheet was also designed to be used by other colleagues who could make an informed judgment based on their knowledge of an individual. However, this questionnaire usually assumed that the observer should know the individual that was being evaluated in depth. This is something that is not always possible to assume in higher education contexts.

3. General tool workflow

In this section, we describe the general workflow of our tool and its most important features. During an academic course, a teacher may carry out several team activities that require the formation of teams. As mentioned above, one of the main problems for teachers is to optimally create teams when there is no previous information about student profiles, and the number of students is high. In the latter scenario, the complexity of determining optimal teams is complex for the teacher due to the exponential nature of the problem [38]. In order to provide support for this team management task, we have developed a software application for teachers that facilitates the costly task of dividing students into optimal or near optimal teams. As a general outline, the application relies on student feedback, coalitional structure generation, and Bayesian learning to form proper distributions of student teams. In the following paragraphs, we will explain how these elements are put together to provide an adequate team formation tool.

It should be noted that the tool has been designed to be integrated in web platforms where the actors (i.e., teachers and students) can interact with the system. We have a standalone web