An architecture for automated group formation within remote laboratories

A. Mujkanovic[1], D. Lowe[1], C. Guetl[2,3] and T. Kostulski[1]

[1]Centre for Real-Time Information Networks
Faculty of Engineering and Information Technology
University of Technology Sydney, Australia
[2] Institute for Information Systems and Computer Media, Graz University of Technology, Graz, Austria
[3] School of Information Systems, CBS, Curtin University, Perth, Western Australia

Abstract— **Group/Team formation has been a well studied field in numerous contexts, (i.e. business teams, project teams, educational teams etc.) but have barely been considered within the scope of remote laboratories. Formation of educational groups in traditional labs/classes often occurs in an ad-hoc fashion where students are assigned to groups mostly without any particular constraints or regard to the group composition that is most likely to lead to optimal educational outcomes. This same ad hoc approach has typified the formation of groups within current remote laboratory environments that involve collaborative groups in remote laboratory settings. There is typically no arbitration for allocating group members to a specific group to perform a particular experiment. In this paper, we consider an approach to automated group formation that continuously analyses group performance and uses this to build rules regarding optimal group composition. These rules can be subsequently used to allocate students to groups that are more likely to have higher performance.**

Index Terms—**group formation, remote laboratories, group allocation, team performance.**

I. Introduction

Remote laboratories have been receiving increasing attention as a valuable educational tool that provides numerous benefits: greater flexibility; opportunities for sharing; potential for cost reductions; amongst many others [1,2]. Remote laboratories and lab systems are increasingly being developed to support group collaboration as part of the laboratory experience [3-7]. In some cases this is in response to logistical or access issues, in other cases it is in response to student preferences. Finding in different studies suggest that such learning settings can be more productive in terms of attitudes of learning experiences, motivational aspects, and student achievements. [8] Regardless of the reasons, a move towards group-based remote laboratories aligns well with traditional educational hands-on laboratories, which are very often carried out as a group exercise [9].

Despite the slowly increasing interest in collaborative remote laboratories, there has been little consideration given to the creation of the student groups that collaborate on the remote laboratory exercises. For example, in Netlab [6,7] where up to three students can book into a common time slot and then collaborate on the laboratory without any constraints or guidance on which students might learn best together. Another example of a lab environment that has incorporated group support but has not considered group formation is the work by Scheucher et al. [10] where remote laboratories are mapped into virtual worlds. Students are represented by avatars and they can work collaboratively but without control or guidance of group formation. A further example is the moodle extension in [11] that allows collaborative lab-work - also without membership arbitration and a systematic allocation of students to groups. An administrator needs to set up an experiment and invite students to perform an experiment. Finally, results from a large-scale remote laboratory trial survey provide interesting insight into the students' perspective on the perceived advantages and disadvantages of group work in this specific context.

In this paper we will consider a novel approach to addressing this lack of support for group formation in remote laboratory settings. Our approach has a particular focus on constructing groups that lead to optimum outcomes against some specified set of criteria. We begin in section II with a literature review on group dynamics including evolution and importance of groups. We compare groups that are natural (i.e. family) with work groups and learning groups and give an insight on group characteristics, structure, efficiency, formation etc. In section III we look at some preliminary work that has investigated student responses to remote laboratory group work. We then use these insights in section IV to propose an architecture for group allocation that addresses the shortcoming we have described. Finally we present our conclusions and discuss future work in section V.

II. Background

A. Group activities

Human beings have always come together in groups for different reasons, for example security, mutual protection, gathering food and developing and passing on the wisdom to the community. Despite this, there is no single understanding of what we mean by the concept of a *group* or the related concept of team.

For example, Edgar H. Schein [12] defines a psychological group as *"[...] any number of people who (1) interact with one another, (2) are psychologically aware of one another and (3) perceive themselves to be a group"*. This definition focuses on the existence of interactions between members of the group. This is in contrast to the description by Bass [12] who emphasizes shared behavior that leads to rewarding outcomes: *"a collection of individuals whose existence as a collection is rewarding to the individuals (or enables them to avoid punishment). A group does not necessarily perceive itself as such. The members do not have to share common goals. Nor are interaction, interlocking roles, and shared ways of behaviour implied in the definition, although these are common characteristics of many groups"*.

There is a disagreement between Bass' and Schein's definitions. According to Schein, a group perceive themselves as a group and individuals interact with each other. Bass contradicts with the statement that groups do not necessarily perceive themselves as a group and interaction between individuals does not indicate a group. As this indicates, a *'group'* is a general concept with significant variation in the characteristics that are assumed to define the existence of a group. [12]

These two examples are just a sample of many others, which collectively demonstrate that there is little consistency in the definition of a group. It is however generally acknowledged (either explicitly or implicitly) that groups will have certain characteristics and will exhibit certain behaviors or *dynamics*, and that these behaviors will affect the extent to which the purpose or outcomes of the group are achieved.

One domain of research that has explicitly considered these relationships is g*roup dynamics*. This only became a significant field of academic research in the 1940s. Since then there has been substantial research carried out in the disciplines of *education*, *psychology* and *sociology* where observations and experiments were made to study group interaction and group development. [13]

One observation that has emerged from a consideration of group dynamics is that there are many different types of groups, with different purposes or objectives and that the structure of the group that is best suited in each case can be quite different. For example, an interesting comparison is made by Adair [12] between families and workgroups. This is summarized in Table II-I. In this case there is a distinction between a task-oriented group and a group that is 'natural'.

Another comparison of *work group* and *teams* by Katzenbach and Smith [14], shown in TABLE *II-II*, argues that the distinction between groups and teams relates to primacy of collective action and outcomes.

TABLE II-I: COMPARISON OF "WORK GROUPS" AND "FAMILIES" (FROM [12])

Work Group	Family
Have a common task	Serve two ends: companionship and the procreation and nurture of children. These are natural and often implicit.
Relationships are functional.	Relationships of parents and children are ontological.
Groups exist to work on tasks.	Families may tackle tasks, e.g. gardening together, but they are expressive rather than intrinsic
Leadership tends to go with competence.	Leadership traditionally tends to go with gender and seniority.
Work groups are often temporary	Family implies a much greater degree of permanence.

TABLE II-II: COMPARISON BETWEEN A "WORK GROUP" AND A "TEAM" (FROM [14])

Work Group	Teams
Strong, clearly focused leader	Shared leadership roles
Individual accountability	Individual and mutual accountability
Individual work products	Collective work products
Runs efficient meetings	Encourages open-ended discussion and active problem-solving meetings
Measures its effectiveness indirectly by its influence on others (e.g. students learning goals)	Measures performance directly by assessing collective work products
Discusses, decides, delegates	Discusses, decides, does real work together

The key lesson for us from these examples is that different types of groups exist because they have different purposes or intended outcomes. Further, because they have different purposes or outcomes they will typically have different characteristics – including structures, membership and/or behaviors.

We can, however, go a step further than this. Not only can we differentiate groups based on the desired purpose or outcomes of the group, but we can also differentiate between groups within different domains. Let us illustrate this by taking a look at groups within a certain context, for example "*work groups*" where it is most likely that individuals of a group have common objectives but (possibly) varying roles within the group. Issues such as leadership, decision making, discipline, loyalty, etc., play an essential role in determining the group structure that is most likely to lead to desired performance and hence to optimize the outcomes [12].

As an example, consider the distinction between business teams and shorter-term project teams. In business teams, the ongoing achievement of the entire team counts and not necessarily what an individual has accomplished, nor is a single outcome sufficient. By comparison, in project teams [15] members do not necessarily have a vested interest in achieving a 'collective' project goal, every project member has very distinct capabilities, and project team members are mostly chosen based on the task to be achieved.

So what does this mean for educational groups in general, and laboratory groups in particular? There is a substantial body of literature that focuses on the purpose, organization and coordination of groups and/or teams within educational settings. Whilst ideally the teams will be established for sound pedagogic reasons, the literature points out that they are very often formed for logistical reasons [16]. Teams can save resources by sharing books, articles, equipment, materials, etc. For example, academic supervision and assessment of a team of five students may be much more resource efficient than supervising and assessing the students individually.

It is also interesting to note that for many (or possibly most) teams in non-academic settings it is the overall *team outcome* that is important. This contrasts with educational contexts, where it is usually the *learning outcomes for each of the individuals* that is most significant. Nevertheless, even though the purpose may be individual rather than team-based, there is still a wide diversity of objectives being targeted through educational teamwork.

In some case the educational teamwork will be targeting general learning support. For example, the following educational advantages may be being targeted: [16]

- Improved performance through cooperation and competitions among groups;
- Improvements in ability to tackle more realistic (i.e. larger and more complex) tasks without becoming overwhelmed;
- Provision of mutual support in the learning process, in terms of peer accessibility, concept relevance, and peer tutoring and peer feedback;

In the context of laboratory-based education many of these issues are even further heightened. Laboratory apparatus and/or physical space and access will often be limited, leading to imperatives for group work within laboratories. There is however surprisingly little research into the educational objectives and desired learning outcomes for laboratories in general. This alone states why group work in laboratories might be desirable – beyond the above-mentioned logistical reasons.

An Accreditation Board for Engineering and Technology Colloquy in 2002 [17,18] described a core set of thirteen objectives for Engineering laboratories. These related to the development of abilities such as applying appropriate instrumentation and tools, identifying the strengths and limitations of theoretical models, and the ability to collect, analyze, and interpret data, as well as many others. Other researchers [19-21] have also confirmed the diversity of learning outcomes that are targeted by laboratory experiences in general. We can take this a step further and consider remote labs specifically. Whilst remotely-accessible labs might have originally been developed for reasons of accessibility or flexibility, the same arguments regarding the diversity of educational objectives still hold true. This is confirmed in an indirect way in the literature on the differences between remote and hands-on laboratories. For example, both Ma and Nickerson [22] and Lindsay and Good [23] have confirmed that remote laboratories can provide *different*, but still quite diverse, benefits from hands-on laboratories.

In other words, what the above discussion suggests is that groups, educational groups in general and remote laboratory groups in particular will have diverse objectives and/or desired outcomes. Further, different outcomes will best be met by different group behaviours and/or characteristics of the group. The natural question that follows from this is how we determine what behaviors and characteristics might be appropriate for a given learning objective. We shall now consider this question.

B. Group behaviour and characteristics

Adair [12] compared a ‘group’ with the term ‘wind’. Wind in climatology is defined as “*…movement of air relative to the surface of the Earth”* [24] but people are more interested in a wind’s characteristics (i.e. velocity, direction, etc.) and how these relate to its effects. In an analogous way we will be more interested in a groups characteristics and how these relate to the outcomes of the group, then the specific group behaviour itself.

If we want to understand groups more deeply, we need to consider them as more than just a monolithic composite, and consider them as a complex aggregate of diverse individuals (i.e. how many people are interacting with each other and the relationship between those members, etc.)

Small groups can indeed be seen as complex systems. The conceptual framework by Arrow, McGrath and Behrdal summarized in [25] models a group by the three elements: members; tasks; and tools. These elements build six different relationships or networks: (1) social networks between members, (2) networks between tasks, (3) networks of tools, (4) role networks between tools and members, (5) labour networks between members and tasks, and (6) job networks between tools and tasks. This complex situation suggests careful planning in the ‘set-up phase’ as well as assessment and support during the ‘performing phase’.

When choosing group members, it is important that every member adds strength to the group and thus increases its effectiveness. Despite this, the construction of the group is often not well managed. For example, typical selection choices for work group members is criticised in [26], where it is observed that group members are often selected by seniority, association, or location. This can result in having people in a group who come up with similar ideas and/or similar decisions.

When selecting the optimum group composition, there are a number of questions whose answers can provide useful insights [26]:

- *What kind of information does the team need to work effectively and who can provide this information? It can be important to ensure that each team contains individuals with knowledge that is important to achieving outcomes.*
- *What skills does the team need and who can provide/develop them?*
- *What cross-functional cooperation can be built and who needs to be on the team to make this happen?*

Beyond considering the individual group members, we can also look at the way in which they operate together to form an effective team. Donelson [27] identified group characteristics including *interaction* (physical, verbal, non-verbal, etc), *structure* (i.e. leader, follower, recorder, etc.), *size* (number of members), *goals* (i.e. developing a product, learning, etc.), *cohesiveness* (strength of relationship between members and the group), *and temporal change*. This latter aspect can be illustrated by, for example, the stages of group development described by Tuckman [27] usually described as: forming, norming, storming, performing. We can illustrate Donelson's group characteristics by considering a soccer team:

Interaction	: physical, verbal, non-verbal
Structure	: captain, goal keeper, etc…
Size	: 11 players
Goal	: win a match
Cohesiveness	: not trivial to identify
Temporal change	: not trivial to identify

In this paper, we are particularly interested in educational groups. Often these groups are very poorly managed – with group members being selected randomly or alphabetically without any particular consideration given to educational objectives. In other cases self-selected groups may be used, resulting in the possibility of groups formed based on friendship, rather than the group characteristics which are most likely to lead to optimal learning outcomes.

While Donelson in [27] does not restrict his group characteristics to a specific context, Connolly gives an insight to group characteristics for learning purposes [28]. Basically, *learning groups* have a common goal (i.e. study) and every member is there for this particular reason – though there may be variations in individual motivations ("I want to pass this course", "I want to learn", "I don't want to disappoint my parents"). Connolly identifies that a learning group contains students who feel connected with each other and perceive themselves a group.

One area of research that is interesting in this context is the use of gaming techniques (i.e. ice-breaking games) [29] to support group formation process. The results reported indicted groups that were more effective in all cases than the randomly and self-selected groups.

This finding may indicate that controlled formation of groups might improve the learning outcomes. Choosing the '*right'* group members and compiling/or/forming groups with a specific *composition* and *structure* can lead to building successful groups [30]. A natural question to therefore ask is how these choices can be made? How can it be decided, for a given purpose (or, with remote-labs, for a given desired learning outcome) what group behaviours and structure might be best?

The answer is not trivial as the group behaviours (i.e. the aggregation of the individual behaviours) will be a consequence of the individual characteristics, the group composition, and the context that is established for the group. The complex relationships between these elements are typically not well understood. This would appear to imply that we cannot therefore easily specify deterministically the optimum group formation for a given desired outcome.

It is therefore useful to ask whether this determination of group formation can be achieved in some way other than through a direct determination based on outcomes. Is it possible to do this through adaptive learning process (i.e. constantly changing group allocation policies)? To provide insight into this question, let us consider these complex interdependencies in more detail and the ways in which different factors affect group outcomes – particularly in the context of our original domain of interest – remote laboratories.

C. Group collaboration and remote laboratories

As discussed above, there can be different reasons for collaboration. These can include logistics, improved productivity, improved quality of outcomes (a typical example is the collaboration inherent in pair programming techniques within agile development [31]), peer support and development (i.e. mentoring), etc.

It is interesting to note that the literature often is unclear about how the team outcome or performance is actually measured or defined or what the actual targeted improvement is. For example, [16], refers to consequences of individual assessment versus group work assessment.

Possibly the biggest distinction to be drawn is that between improving the outcome for the group as a whole and improving the outcomes for the individuals participating in the group. There is significant literature that talks about increasing the success of the team, and the factors that are likely to affect this success. An example of this is Hackmann's [27] *normative model of group effectiveness* as illustrated in
FIGURE 1 below.

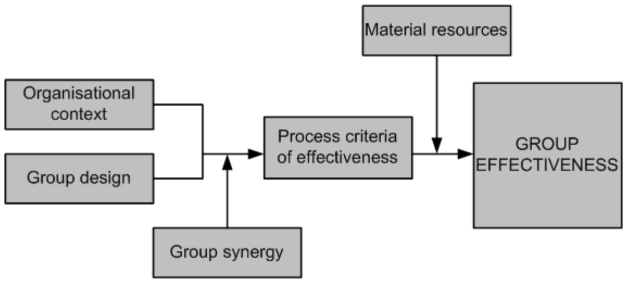

FIGURE 1: HACKMANN'S NORMATIVE MODEL OF GROUP EFFECTIVENESS [27, p. 277-280].

In Hackmann's model, the affecting factors include:

- *organisational (*supports and reinforces task work via reward-,education- and information system*),*
- *group design* (allows a quick, easy and competent group work via structure of the task, composition of the group, group norms about performance processes).
- *group synergy* (supports the group interaction to reduce process losses and to create synergetic process gains.)
- *process criteria of effectiveness* (includes level of effort)
- *material resources* (sufficient material resources that are needed for the task to be finished on time)
- *group effectiveness* (acceptable task for those who receive and review it; capability of members to work together in future should be strengthened; group members needs are more satisfied than frustrated)

Hackmann's model gives us some useful insights into the interplay between the different characteristics, and hence what elements we might want to measure or manage if we are to try to construct optimal groups. In the context learning groups (either generally, or specifically for remote laboratories) we can map Hackmann's model to a *LEARNING OUTCOME MODEL* that captures the dependencies between group characteristics and learning outcomes shown in *FIGURE 2*.

One observation from *FIGURE 2* is that the learning outcomes for each student will be affected by both their behaviour within the group and the context that has been established for their learning. The individual behaviours will, in turn, be affected by the context (e.g. the task they have been set, the form of assessment that they expect, the environment in which they are operating, etc.), the structure of the group (e.g. who else they are working with and how the group is organised), and the characteristics of the individual students (i.e. age, previous knowledge, personality, cultural background, gender, etc). Note that we don't explicitly consider the collective group behaviour, but rather the individual behaviours within the group that leads to learning outcomes. Whilst individual characteristics might be dynamic over time (e.g. a student might develop into a more independent learner) we can consider them as relatively static within the context of a single laboratory experience. We can hence treat this as student meta-data that might be an input into any group allocation determination. In contrast, the *context* and *group composition* are both aspects that we may have some control over hence would be outputs from our group determination process. In other words, we could potentially determine, for a given pool of students with certain characteristics, what group composition or task context we might create that would lead to certain individual behaviours, and hence to desired learning outcomes.

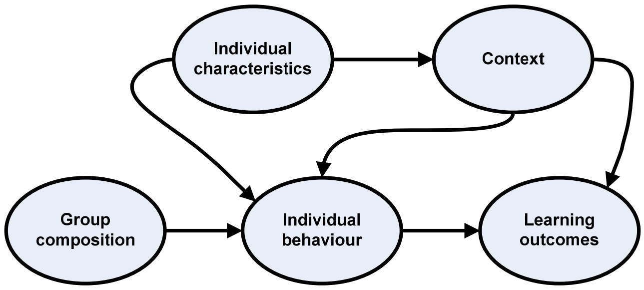

FIGURE 2: LEARNING OUTCOME MODEL

Consider what this might mean in a practical system. Students are registered for participation in a group-based learning task (e.g. a remote laboratory session) and our system then finds the group members, and creates an experimental context that is most likely to achieve desired learning outcomes.

Collaboration is often, but unsatisfactory defined as 'two or more' people learning something together. "Two or more" can be interpreted as a pair, small group (3-5 students), a class (20-30 students), a community (a few hundreds of students) etc. "Learning something together" could mean those students follow a course, study course material or learn problem solving techniques either face-to-face or through means of Information Technology. [32]

Remote laboratory groups might range in size from pairs and small groups (3-5 students) to larger groups (6-12 students) interacting through the remote laboratory web interface. The general advantages of collaboration can be broken down into three major categories [33]: academic benefits; social benefits; and psychological benefits.

In the absence of much research into group work in student laboratories, it is worthwhile looking at the outcomes from a study that included consideration of student preferences on group work.

III. STUDENT PREFERENCES – AN AUSTRALIAN CASE STUDY

Having investigated the theoretical aspects of group learning in a remote laboratory setting, it is worthwhile to look at the student perspective. The advantages of a well-structured group learning experience are not always well communicated to students, but their willingness to engage is even more important in a remote setting without direct supervision, compared to a classroom environment. Besides, the very benefits that make remote laboratories attractive to students, such as convenience of access and flexibility, may be affected when introducing group work.

Between August and November 2010, the Australian Labshare project invited several academics from 6 Australian universities to participate in a national sharing trial of 6 different remote laboratory experiments. Half of those academics had used remote labs in their coursework before, the other half was completely new to the concept. While Labshare provided technical and administrative support, the pedagogic delivery was entirely in the hands of the respective academics. It must be noted that the remote experiments used in this trial did not have any inherent features in support of group work, such as multi-user session capability or passive monitoring. Students came from a wide variety of engineering disciplines, and class sizes ranged from 12 to 250 students.

Ten classes with almost 1,000 students from 6 universities participated in this trial and were invited to provide feedback in an anonymous, voluntary online evaluation shortly after the completion of their trial. Participants came from major metropolitan and smaller regional universities alike. Out of 171 survey responses received, 148 (87%) were deemed valid, which can be seen as a sufficient sample size for statistical analysis. Further details about the trials and the overall outcomes of the student evaluation can be found in a companion paper [34].

Within the current context, we will now look into only one specific question that captured the students' responses and comments pertaining to group work (amongst many others). The majority of assignment tasks was reportedly given on an individual basis. Only one academic with a class of 110 (who had never used remote laboratories before) decided to let the students conduct the remote experiment in *pairs*, which now provides an interesting case for comparison to the remaining participants.

TABLE *3* summarises how students responded to either the hypothesis of, or the experience with, a remote experiment involving group work. At first glance, it appears that the majority of participants were content with *their* particular mode of participation: almost 60% of students who had worked individually preferred that mode, and students who had worked in pairs were even more satisfied with their experience. However, the overall opinion is very evenly split: having actively used remote labs in assessable coursework, one-half of the students are in favour of group work, the other half prefer to work individually. It is interesting to note that over two-thirds of all respondents felt compelled to justify their answer further, especially to argue the perceived conflict between remote labs convenience and group work. The open-ended comments that students left provide a much deeper insight into the reasons for their choice.

TABLE 3: STUDENT OPINION ABOUT GROUP WORK IN REMOTE LABS

<u>Question:</u> *"Would you have preferred, or did you prefer, a remote labs experiment involving group work?"*

	Individual		Pairs		All students	
Response	Count	Percent	Count	Percent	Count	Percent
Yes	41	41.1%	34	69.4%	75	50.7%
No	58	58.9%	15	30.6%	73	49.3%
Total	99	100.%	49	100%	148	100%

Typical comments in favour of individual work include:

"I could work at my own pace with no real time limit."

"Doing it individually ensures that you fully understand the concepts yourself, and it is more satisfying."

"I like to make my own mistakes - and find my own solutions."

"In group experiments, one person will often do everything and it is hard to see what is happening and hard to learn from it."

"The best thing about this lab was the time convenience. Working in a group would have limited this somewhat and in my opinion the most benefit (learning) is gained from performing the experiment individually."

"Working as a group around one experiment can be difficult. But it is worse to have a group crowding around a terminal."

"Problem-solving is sometimes easier when working individually. With group work, if there's a glitch by one person, it will affect everyone."

"Teamwork is not fair enough."

Some comments that support a group work approach are:

"Since there is no lab demonstrator, it is better to work together."

"Engineers must get more experience with teamwork and team cohesion."

"It is more fun and the learning process is better when you work in groups."

"We did it as a pair; it was good having someone else check that everything was going OK."

"We had many discussions and helped each other."

"We learned from each other because we could split the work and discuss any issues we encountered."

It is evident that most students have fully embraced the convenience factor that remote labs provide. Group work is predominantly seen as having a negative impact on their flexibility and individual achievement, which comes down to the preferred learning style of the individual students. On the other hand, group work is recognised as a valuable learning tool for *some* students, as partial compensation for the absence of a demonstrator, and also as an essential skill that all engineers should learn, despite any alleged individual disadvantages.

Looking critically into the origin of the comments that were unsupportive or critical of group work, it is interesting to learn that the majority of those comments originated from students who had not actually worked in pairs at all – and had therefore given a *hypothetical* answer only. The overwhelmingly positive experience (~70%) of those students who *did* actually work in pairs during the trial illustrates that group work can be successfully applied to remote laboratory environments – in a way that preserves its benefits. How this was achieved by the participating academic was not part of the trial evaluation, but is currently followed up on.

This example suggests that the convenience and learning preferences of the *individual* student should form part of the meta-data which facilitates the group formation process and which should guide the pedagogic design of the laboratory experiment. The student evaluation also found that 91% of all respondents would like to see either many or a few more remote experiments in their coursework, providing further support that this topic is worth investigating.

IV. Proposed Group Allocation Approach

As distinct from other approaches that incorporate some form of group allocation processes in laboratory settings, we are proposing an approach that utilises 'intelligent' group formation within the scope of remote laboratories. The aim of this approach is to construct groups that have increased effectiveness against a range of definable metrics.

An earlier version of our approach, introduced in [35], supports grouping students by using *meta-data* about each student combined with a set of *allocation policies*. This information is then used to make decisions on group membership. Once groups have been formed they are able to access the remote laboratory system and work collaboratively on diverse remotely accessible experiments. A boundary model illustrates this idea in Figure *3*.

In this section we will focus on an extension to this earlier approach which addresses the questions raised above. In particular we consider whether it is possible to construct a learning system that progressively improves the student allocation process.

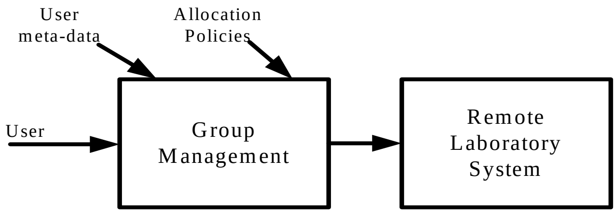

Figure 3: Boundary model of group management and remote laboratories

This is achieved by continuously evaluating group performance outcomes, and correlating these outcomes against the characteristics of the group in order to adjust the allocation policies towards constructing groups that have optimal performance. The conceptual architecture used to support this approach is illustrated in Figure 4.

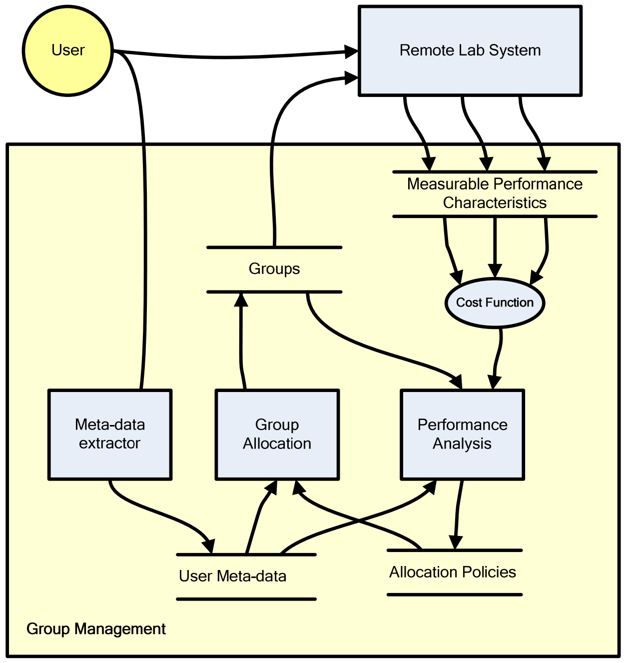

Figure 4: Group allocation Architecture

The significant change in this architecture over that described previously is the inclusion of a performance analysis mechanism. A range of performance characteristics are measured from the remote laboratory system. These provide a set of measures that can be used as indicators of functioning of the overall group. Whilst our approach is not prescriptive about what measures might be used, examples include: *level and diversity of chat dialogue; group member pre-test and post-test results; student time on task; total time to completion; diversity of experimental control; balance of experimental control between group members; number and nature of requests for assistance; parallel access to laboratory guide notes;* etc.

The actual balance of performance characteristics that might be desirable is likely to vary from experiment to experiment – depending on the context and desired learning outcomes. For example, with a laboratory that aims to develop a critical understanding of the limitations of model of dynamic behaviour, a higher level of dialogue between group members that focuses on analysis of the data being generated might be desirable. In another case where the laboratory is focused on developing skills in the use of instrumentation we may wish to see a balance of all group members spending time controlling the equipment.

In other words, the specific performance characteristics that we wish to see will be likely to vary from experiment to experiment. The actual desired balance of characteristics that is appropriate for a given circumstance is beyond the scope of this paper (and might typically be drawn from existing literature). Rather, we are interested in an approach that allows us to specify *any* balance of characteristics (in effect defining a composite *group effectiveness* characteristic), and have the system automatically optimise the groups against that particular composite characteristic. We achieve this by providing for the definition of a cost function that is some weighted combination of the performance characteristics. In our initial evaluations the cost function is treated as a simple linear weighted combination of the performance factors f_i, as follows:

$$\textit{Group Effectiveness} = \sum k_i * f_i$$

The cost function (i.e. the performance characteristics weights) would be defined separately for each experiment – in effect providing a composite measure of the overall group effectiveness for a given experimental objective.

We can then use this measure of *group effectiveness* to progressively refine the allocation policies. This would be achieved by correlating the group effectiveness against the characteristics if the group – drawn from the meta-data on the individual group members. The result will be progressive adaptation of the allocation policies over time that lead to the construction of groups that maximise the group effectiveness defined for that particular experiment. The more groups that have been monitored the more data will be collected and the more effectively we will be able to construct groups. Group allocation policies will change over time. If academics wish to grade certain skill more, they can weight for example the *post test* more than the chat dialogue.

Key challenges in implementing this architecture will be determining the best algorithm to use within the performance analysis and determining the best policy language to encode the group formation rules. A further challenge will be gathering real data for analysis and finding an automated way how to adapt those groups formation rules.

We have previously seen that the literature does not presuppose what individual characteristics can be used to construct groups that lead to positive outcomes. Therefore, we will investigate through dynamic creation of allocation policies if there are correlation between, individual characteristics, user interactivity that occurs during experimentation and results of remote laboratory learning outcomes.

V. CONCLUSION AND FURTHER WORK

Despite the logistical advantages of remote laboratories such as the sharing of resources and increased flexibility, pedagogical aspects also need to be considered in order to improve their effectiveness. One way of incorporating this could be by supporting students to work in groups. Some current remote laboratories support group work but have not yet explicitly considered the group-formation process.

In order to form effective groups it is important to understand that there is no single definition of the concept of a group. Different types of groups will exhibit certain characteristics (i.e. membership, structure and behaviour) during their lifetime and they exist for a particular intention. Therefore it is not feasible to have a single set of rules defining the group formation that would be universally applicable.

There are many reasons for adopting group work but despite all of them, our national survey showed that students preferred working collaboratively which alone makes it worth investigating this topic further.

This paper introduced an architecture for an automated group allocation within remote laboratories. It uses user's meta-data and group allocation policies to construct groups that are more likely to lead to high learning outcomes. The group formation process will be supported by an ongoing performance analysis of groups and a dynamic update of the group-allocation policies. Those policies are based on individual- and group characteristics correlated against group performance measurements from the laboratory sessions and eventually with the final test results. The data that this architecture is going to produce will show insight into characteristics and behaviour of remote laboratory groups and thus improve learning in this particular context.

Further investigations include finding a policy language that can be used within the group allocation process and finding the best suitable algorithm that dynamically creates those policies.

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AUTHORS

A. Mujkanovic, is with the Faculty of Engineering and Information Technology, University of Technology, Sydney; Australia;

(E-mail: Amir.Mujkanovic@student.uts.edu.au).

D. Lowe, is with the Faculty of Engineering and Information Technology, University of Technology, Sydney; Australia;

(E-mail: David.Lowe@uts.edu.au).

C. Guetl, is with the Graz University of Technology and Curtin University, Perth, Western Australia

(E-mail: Christian.Guetl@iicm.tugraz.at).

T. Kostulski, is with the Faculty of Engineering and Information Technology, University of Technology, Sydney; Australia;

(E-mail: Thorsten.Kostulski@uts.edu.au).

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