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Realism and Control: Problem-Based Learning Programs as a Data Source for Work-Related Research*

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Problem-based learning (PBL) is a pedagogical methodology that presents the learner with a problem to be solved to stimulate and situate learning. This paper presents key characteristics of a problem-based learning environment that determines its suitability as a data source for work-related research studies. To date, little has been written about the availability and validity of PBL environments as a data source and its suitability for work-related research. We describe problem-based learning and use a research project case study to illustrate the challenges associated with industry work samples. We then describe the PBL course used in our research case study and use this example to illustrate the key attributes of problem-based learning environments and show how the chosen PBL environment met the work-related research requirements of the research case study. We propose that the more realistic the PBL work context and work group composition, the better the PBL environment as a data source for a work-related research. The work context is more realistic when relevant and complex project-based problems are tackled in industry-like work conditions over longer time frames. Work group composition is more realistic when participants with industry-level education and experience enact specialized roles in different disciplines within a professional community.

INTRODUCTION

THE GOAL of this paper is to present the key characteristics of a problem-based learning (PBL) environment that influence its suitability as a data source for a work-related research study.

Problem statement

The use and diversity of PBL environments as a pedagogical methodology are increasing. The use of PBL environments as a data source for work-related research studies is also increasing.

Whereas the usage and diversity of PBL environments is increasing, little or no analysis has been done to determine how this data source compares to the use of other student or work place samples. This means that when considering a PBL data source for a research opportunity or when evaluating a PBL data source that has been used in a study, there are no guidelines to follow and a bewildering array of PBL options to consider.

Trust and PBL

We use a research study of trust in cross-functional, global teams to illustrate the challenges of using an industry data source. The Computer Integrated Architecture-Engineering-Construction (A/E/C) course in Stanford University's Civil and Environmental Engineering Department [1] illustrates how a PBL environment can provide a useful alternative to industrial field studies or traditional kinds of synthetic experiments with students. Based upon our case study, we identify the attributes of the PBL environment that affect the suitability of the PBL as a data source for work-related research studies.

Problem-based learning is a pedagogic methodology that presents the learner with a problem to be solved to situate the learning. The learner actively engages in framing the problem [2], identifying and gathering resources, and working with others to solve the problem.

Problem-based learning is sometimes called:

- project-based learning [3] when the problems are organized around a project;
- product-based learning [4] when the problem is focused on product design;
- team-based learning [5] when the problem is worked upon by a group of students;
- problem, project, product, process and people-based learning [1] when all these aspects are engaged.

Problem-based learning can be more similar to work-place learning than conventional University learning [6]. Work-place learning is more social than

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individual, uses the 'tools of the trade' rather than pure mentation, involves contextualized reasoning rather than manipulation of symbols and results in specific learning rather than generalized learning [6].

The use of problem-based learning is increasing in the education of students for professions engaged in the application of specialized skills and, simultaneously, as a research data source. Problem-based learning is being applied in the education and/or research of:

- business managers [7]
- teachers [8]
- principals [2, 9]
- geographical information systems designers [5]
- mechanical engineers [4]
- civil engineers and architects [1]
- medical and veterinary science practitioners [10].

There are many different problem-based learning courses, each with different characteristics, which could impact upon the suitability of a PBL environment as a research sample. This makes it difficult to assess a PBL environment as a potential data source for an experiment, or to assess the use of a PBL data source when evaluating an empirical research study.

In this paper, first we describe a research project that we use as a case study to illustrate the characteristics of PBL environments. Then we describe the potential data sources and analyze the PBL environment as a data source for a work-related study. We discuss the advantages and disadvantages of using a PBL data source compared to an industry sample. The PBL data source chosen for our research project is then introduced and used to illustrate the key characteristics of a PBL environment as a data source for work-related studies. We then discuss the pedagogic advantages and limitations of using a PBL as a research data source. After our closing discussion of the contribution and limitations of this work we suggest future research.

THE RESEARCH STUDY

Trust in cross-functional, global teams

Internet technology makes it feasible for firms to assemble and operate cross-functional, globally distributed teams. Although companies are rapidly adopting the model of cross-functional, global teams, little is known about the challenging new social environment that this creates for team members. One challenge may be the development of trust. Trust is necessary in cross-functional, global teams because team members must depend upon each other to provide their specialized skills. At the same time, it may be difficult for interdependent team members to develop trust because of different disciplinary perspectives, regional or national cultures, and the lack of face-to-face interaction when working at a distance. Our research question was:

Which variables, when evaluated together, are the key predictors of trust in cross-functional global teams?

The goal of the research study was to test a model of interpersonal trust development [11].

Our model of trust was based on six different theories of trust development. When those theories were integrated into the model, the variables that we used to predict trust were: the general disposition to trust of the trustor, the extent to which the trustor perceived risk and reward in the situation, and the perceived trustworthiness of the trustee. We also proposed that the more the trustor perceived that the trustee followed through in the past; the higher would be the trustor's perceived trustworthiness for the trustee in the future. We needed measures for these variables and we needed a measure for trust that took into consideration a key issue, the object of trust. Hardin says 'A trusts B about X'. Our measure of trust needed to be measured at the interpersonal level and take into consideration the nature of 'X'. At the time of starting our research project, there were no published scales to measure the variables we required. Therefore, we first had to develop an initial model with scales to operationalize the model variables. Then we had to test the scales. Finally, we had to test the model longitudinally to see if it correctly predicted changes in trust over time.

DATA SOURCES

Natural, semi-natural and artificial settings and artifacts

There are four different data sources from which a researcher can gather data for work-related studies [12]:

- natural social settings
- semi-natural settings
- artificial settings
- artifacts.

Gathering data in a natural setting involves observing people as they go about their everyday lives, for example ethnographic techniques can be used to observe subjects at work. Gathering data in a semi-natural setting involves asking people to report on their activities, for example surveying workers. In an artificial setting, social activity is organized to simulate real life for experimental or learning purposes, for example inviting subjects to a sociological laboratory and asking them to behave as they would at work for a couple of hours. Artifacts also provide data, for example company records.

Experiments have the advantage of providing a means to isolate the key experimental variables [13] through the creation of an artificial testing environment. In a classical experimental design, the sample is divided into the experimental group and the control group. The dependent variable is measured before the experimental stimulus is applied to the experimental group, but not the

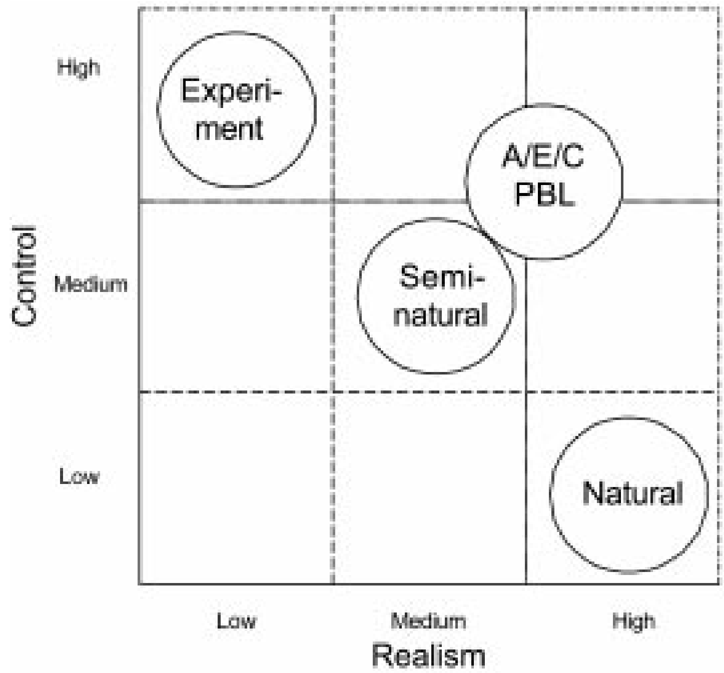

Fig. 1. Control and realism of natural, semi-natural, experimental and PBL settings.

control group. The dependent variable is measured again afterwards, and the results of the experimental group are compared to those of the control group. The disadvantage of experiments is that, due to the fact that these are artificial tests, their relevance to the real world is always questionable [13]. Participants are aware that they are participating in an experiment and may not necessarily behave the same as they would in normal life. Thus, compared to natural and semi-natural settings, experiments are high on control but low on realism (see Fig. 1)

In contrast, in a natural setting the researcher observes the subjects as unobtrusively as possible. The researcher does not instigate events to represent the independent variable and variables are measured through observation rather than questioning. This option is high on realism but low on control because the events of interest may not occur naturally during the observation period (see Fig. 1). When subjects are questioned in the semi-natural setting, control is higher than in a natural setting because the researchers can ask any questions they need to measure the variables of interest. Higher control is offset against reduced realism, because such questioning does not happen in a natural setting and the act of questioning can bias the subject's responses [14].

Analysis of PBL as a data source

This section considers the type of data source PBL represents in a work-related study, such as our research study of trust in global teamwork.

If the population of interest consists of students in PBL courses, then the study of those students using observational methods provides data gathered in a natural setting. The students were observed in the normal course of their day. If questionnaires or surveys are used, the data source is gathered in a semi-natural setting.

In contrast, if the population of interest is people at work, then the students in a PBL course represent a data source in an 'artificial setting'. The student's activities look like work, but they are structured for their educational benefit.

Because the PBL environment is an artificial setting, we have the advantages of greater control of the subject's environment, with the corresponding loss in realism. Nevertheless, compared to the traditional laboratory experiment, the PBL environment can provide a higher level of realism as we demonstrate using the case study.

Challenges in using work-related data sources

Work-place sampling can be difficult, impractical, time consuming, and, in some situations, impossible if the intrusion caused by the researcher is deemed to be too high. For example, it is unlikely that a technical sales engineer, who has worked for many months to arrange a sales presentation for a high value equipment installation, would agree to have a researcher present at that critical sales meeting. Whereas incentives can be offered, the size of the incentive would have to be extremely high and that would change the nature of the interaction being studied.

Low motivation

If the respondent is surveyed at work, cooperation is required from the company as well as the individual. Higher levels of research intervention are very difficult to achieve in a working environment, because the company is concerned with the effect on worker's productivity and individuals may have little or no motivation to respond. The company and the subjects need high levels of motivation to justify taking time away from work to participate in a research study. Low motivation can cause problems, such as low response rates, incomplete responses and inattentive survey responses, but high levels of incentives to counter low motivation reduce realism by changing the incentive structure in the work environment.

Organizational change

Work-place samples also suffer from unexpected events, such as restructuring, mergers and take-overs that may change the organizational unit under observation or destroy it before the study is complete.

Workforce turnover

Industry workforces generally experience turnover, which can be as high as 25% per year or more. Workforce turnover is a problem in longitudinal studies where the research requires the survey of the same individuals at two points in time.

Low motivation, organizational change and workforce turnover make it difficult to recruit sufficient workers to obtain a statistically significant sample size.

Advantages of student samples

The difficulty of collecting work-place data makes it advantageous to find suitable alternative data sources, particularly for time-consuming research activities such as the development of scales and data collection instruments and testing of longitudinal models. An industry work-place sample is obviously more representative of the population of workers than a student sample, but when work-place samples are unavailable or when the level of involvement is unrealistic for a work-place commitment; a student sample may provide a reasonable alternative. After the scales and model have been tested and refined using the PBL sample, validating them with an industry sample is a simpler exercise.

University students are a research population that is widely used by researchers because they are close at hand to faculty, and are readily available in large numbers [13]. Students are relatively easier to recruit for research than the general population because students may have an interest in research, an expectation to participate in research as part of a course, or they may find the small financial incentives more motivating than the average full time worker. Due to this higher motivation, students are often willing to provide more information and tolerate greater interventions (e.g. longer or more frequent interviews or surveys) than an industry sample. The concentration of students in large numbers also facilitates recruiting. Many researchers recruit new universities students attending entry levels classes to participate in surveys and experiments. Although the higher motivation of university students can bias the student's response, this can be avoided with careful research design and practices.

Human Subjects Guidelines require participation to be voluntary and students cannot be encouraged to participate by threats or rewards in terms of grades.

STANFORD UNIVERSITY'S A/E/C PBL TEAMS

In our study, we were interested to see whether our model of interpersonal trust validates for the student population, but of even greater interest is the generalization of the results to the population of workers in cross-functional, global industry teams. Thus, for our study the PBL data source represents an artificial setting, like that of an experiment.

To build and test a model of interpersonal trust in cross-functional, global student teams we studied students in cross-disciplinary building design teams. The participants for this study were students in the PBL course 'Computer Integrated Architecture-Engineering-Construction', organized by Stanford University's Department of Civil and Environmental Engineering [1]. It is a project-based course in which global teams of architecture, structural engineering and construction management students design, analyze and plan a \$5 million, 30,000 square foot university building. All teams had at least one team member who was not on the same campus and most teams had at least one team member in a different time zone. A unique aspect of this course is that it enrolls students from Stanford and several other universities around the world, giving students the opportunity to experience global teamwork in a distributed environment. The course takes place every year from January to May.

We began our research project with the observation of the A/E/C PBL teams at work to better understand the respondent's understanding of trust in this context [12] and identify suitable ways to measure the hypothesized variables of the trust study, e.g. perceived trustworthiness or perceived performance. The study took place in three phases over three years. In year 0, prior to developing a model of interpersonal trust in global teams, we used ethnographic techniques to observe the global teams, and we conducted group discussions with each of the three A/E/C disciplines. We observed and videotaped, from a single location at Stanford University, the distributed team meetings. We conducted group discussions with all participants in each of the three disciplines to develop a general understanding of how trust developed, and to identify strategies for data collection. From this we built our initial model of trust and developed surveys to operationalize the model variables

In year 1, we studied seven teams composed of three to four team members each, distributed across six locations in three countries—the United States, the United Kingdom, and Slovenia. Over five months, we observed and videotaped one side of the distributed team meetings, conducted structured interviews with individual team members, and administered two surveys at two points in time to triangulate the measures [12]. During the first two weeks of the project, we administered an online survey with questions about work experience, the number of courses taken in each discipline, and general trust. Three months into the project, we asked each team member to rate each other team member on the dimensions of perceived trustworthiness, care and ability, to evaluate performance and to indicate the extent to which they checked on the work of each other team member (i.e. our measure of trust). Information on the trustor's perceived risk and reward and the trustor's perception of the trustee's risk and reward were gathered from structured interviews conducted during the last month of the 4-month project. The interviews were video taped and notes transcribed.

The data collected in year 1 allowed us to test and refine the model. We found that some variables, such as disposition, were not significant and dropped them from the model.

In year 2 we tested the refined model, using our revised scales. We conducted online surveys and structured interviews with members of 12 teams composed of three to four team members each, distributed among 10 locations in six countries—the United States, Switzerland, Holland, Germany, Slovenia, and Japan. In year 2, as in year 1, a survey during the first week of the project asked questions about the number of courses taken and work experience in each discipline. We also added questions about students' perceptions of their own risks and rewards associated with the project. This allowed us to measure risk perceptions independent of the personal interactions that would occur later in the projects. Approximately one month later and three months later, we distributed dyadic surveys similar to that described in year 1. This allowed us to compare the model variables at two points in time. The use of three surveys also helped us to avoid the 'common methods problem' that can be caused by gathering all variables from the same survey instrument.

Thus, we observed the same PBL, operating in the same environment, over a period of three years. This allowed us to develop and test the model in an iterative process.

KEY CHARACTERISTICS OF A PBL ENVIRONMENT

The following section identifies and discusses the key characteristics of a PBL course as a research sample in a work-related study. Some of these attributes have important pedagogic value affecting the achievement of the educational goals of the PBL course. The optimal design of a PBL course to achieve the research goals may conflict with achievement of the course's pedagogic goals. The resolution of this conflict depends upon the relative value placed on the educational and research goals. The impact of these specific PBL characteristics on the pedagogic value of a PBL environment is beyond the scope of this paper, although general pedagogic advantages and constraints are addressed later in this paper. It is the authors' opinion that, in general, most PBL attributes that increase in the realism of the learning experience are likely to contribute to the achievement of the PBL's educational goals.

The problem similarity

If the problem being tackled in the PBL environment is widely different for each student or team, more variables need to be gathered to control for the task differences, such as task complexity or the level of innovation required. In a work-place sample, the researcher can select, but not control the task being studied. In a PBL, the researcher can assign teams to essentially the same task and thereby minimize the number of variables that must be collected to control for task differences.

For example, PBL teams practicing consulting skills could be asked to solve the same case study problem or they can be asked to find different organizations with problems to be solved. In the second situation the level of difficulty of the problem could be quite different from one team to the other.

The A/E/C PBL task; 'to design, analyze, and plan a university building', was essentially the same for all teams but each team was assigned to design a building for a different location, for example a river site, an ocean site, or a site in the mountains. The site difference made the work more individual and realistic, as the teams had to consider the impact of the site on the final design, but the site difference did not significantly change the level of difficulty, nor the essential steps or their sequence, in the project. Therefore we did not feel it necessary to collect data on task characteristics, such as the relative difficulty of the task, or the level of innovation required.

Group assignment procedure

Non-random group assignment procedures, such as assignment based on student preferences [8], can introduce bias. If the group is the unit of analysis, team self-selection means that individual characteristics, such as ability, education or experience, are unlikely to be evenly distributed among the groups. Non-random group assignment procedures may be particularly problematic if the group is the unit of analysis for the research, of statistical methods are being used to analyze the results or if team performance is being measured. Random assignment does not create teams with equal skills. It is designed to provide a normal distribution of skills in teams created. This is necessary for the use of statistical methods, which are based upon the assumption of a normal distribution of characteristics in the sample [15]. Therefore, if the students are allowed to choose their own team partners, the academically stronger students are likely to group together, thus creating teams with an uneven distribution of skills and personality characteristics. Alternatively, the educator may assign students to teams based on certain assessments of skill or experience. This is a very difficult process and due to the uneven distribution of skills in a class, is unlikely to create teams with equivalent skills. Whereas assignment by skill level may reduce the unevenness of skill distribution, it may introduce bias other ways.

In our case study, the A/E/C PBL students were randomly assigned to groups during the initial face-to-face meeting attended by all students. Each project had a specific characteristic, such as being located in an earthquake zone. Skill profiles that described past experience, such as experience working in an earthquake zone, were distributed randomly to students of each discipline, e.g. architecture profiles to architecture students. In an icebreaking exercise, students identified and joined the project that best suited their randomly assigned skill profile, for example, the student with experience working in earthquake zones would join the project located in an earthquake zone.

This meant that, in general, we could assume a normal distribution of skills and abilities. We tested that assumption and found that it was close to normal for the data that we collected on number of courses and years work experience.

Continuity

One of the challenges of our trust study was finding the opportunity to build and test our model through several iterations. Few organizations are patient enough to endure being the subject of a research study that extends over successive project generations.

PBL courses are usually replicated on an annual basis. That provides the opportunity to observe successive classes of students working in the same environment, on the same problem.

In the A/E/C PBL environment, we observed the teams over three consecutive years and collected survey data for the last two years. We were able to repeat our test of the model through several iterations and improve it by dropping variables, such as dispositional trust, that did not prove significant and testing new variables, such as integrity. This allowed us to refine and adapt our research model and data gathering tools. Then, when our tools were mature, we could take our study into the work place.

The sample size

Low motivation and other problems sometimes make it difficult to get a sufficiently large sample size for statistical analysis in work-related studies. Calculation of the sample size depends upon the research unit of analysis; for example, teams, dyads, directional dyads or individuals. Generally speaking, the research techniques employed should be appropriate for the size of the potential sample. Some PBL classes may be more suited to a case study approach because the class size is small or because the unit of analysis is the team rather than the individual or dyad.

In our case study, the unit of analysis was the directional dyad. A dyad consists of two people, person A and person B. A directional dyad is the attitude of person A about person B. In any team of n team members there are $n(n-1)$ directional dyads. Therefore in an average team of three team members there are six directional dyads.

Each year all team members participated in the research. In year 1 we received 61 usable directional dyadic responses (e.g. responses from A about B). In year two our surveys yielded 108 directional dyadic responses. Thus we were able to perform statistical analysis on the data and find some significant results.

PBL work context attributes

One of the criticisms of PBL environments as a work-related data source is that the students do not have the same motivations, risks and rewards, as typical industry workers. We propose that the more realistic the work context created in the PBL environment, the more valuable the PBL as a work-related data source and the more generalizable the results. The following work-context attributes influence the realism of the PBL environment.

Exposure to the professional community

Whereas providing a safe environment to experiment, PBL environments can also shield students from the culture of the professional community with it's associated risks. Whereas the pedagogic benefit of learning the culture of one's chosen discipline seem clear other associated risks and rewards may not be. When the student knows that the performance of the group will be observed by an industry professional, there are professional risks to non-performance and conversely potential rewards for good performance. Therefore, a PBL project based upon a case study where the student has no necessity to contact industry provides no need to ensure that one's questions and behavior fit the professional community's standards of behavior. In contrast, a PBL that requires students to interact with industry provides the opportunity for future employment if the student's work is sufficiently impressive.

The A/E/C PBL students were encouraged to consult with the faculty and industry mentors to help solve their technical problems. This close working relationship with respected industry professionals made the A/E/C PBL a bridging experience between study and work. PBL courses can develop the student's sense of professional development and identity [8]. The A/E/C PBL students were well aware that the industry mentors were viewing their work on the project and may recruit them for permanent professional jobs. This introduced the 'Shadow of the Future' [16] that exists in professional work. The worker knows that his or her performance in the current relationship affects the way the other person will treat him or her in the future.

The problem relevance

The less relevant the PBL problem or project is to the referent work place, the less generalizable will be the interactions observed in the PBL environment to the work-place population. Conversely, the more relevant the problem appears to be to the student's future work goals, the higher will be the level of realism. For example, if the problem is a mathematical calculation, it could be perceived to be irrelevant to a structural engineering student, unless it is shown to be relevant to the design of a beam.

The A/E/C PBL project was the type of assignment the students could expect to get after working for several years in their field. Overall the project had high relevance for the students and the students were observed to behave in similar ways to what we would expect in an industry setting. For example, we heard the student construction managers make similar comments about the architecture students to those heard from construction managers in industry.

The problem complexity

If the complexity and diversity of the problem, or project is significantly lower than that encountered in industry, the level of realism is reduced. For example, a project such as writing a memo to give advice to a manager is less complex problem than to discuss such a proposal with a manager from a specific company [17] and is likely to be perceived to have less realism. Macdonald and Isaacs identify the difference between isolated problems and a 'meta-problem' that provides 'continuity and depth in terms of the student's focus, resources and questions.' [8, p. 328] The meta-problem is likely to be more real and engaging than an isolated problem.

The problem for the A/E/C PBL project was to design a five million dollar building according to a client's specifications. The challenging 'real-life' complexity, nature and size of the problem meant that we were able to observe many interactions, such as relational and task conflicts that we know occur in industry workgroups.

The time frame

PBL projects that only operate for short periods of time are less likely to be perceived as realistic by the participants. A longer time frame provides enough time for the participants to change their work habits, thus making a longitudinal study possible. One of the proposed effects of problem-based learning is the development of a professional identity [8]. A longer time frame also allows professional identities and relationships to develop, as they would in a real work environment.

The A/E/C PBL teams operated over a period of five months from January to May. This allowed the students to live with the problem and change their work habits, relationships and identities. This was especially relevant when studying social processes that extend over time, like the development of trust. This long time frame allowed us to conduct a longitudinal study by surveying in month 1 and month 3. We found significant differences at these two different time periods that could not have been detected had the project only lasted one month. The longer time frame also allowed for different data gathering techniques to be used, providing a rich collection of data seldom seen in work-place studies. The ability to collect data using more than one instrument can help the researcher to avoid common methods variance [14]. Common methods variances can occur when the same instrument is used to gather to all the independent and dependent variables and answers to previous questions prime subjects to provide similar responses to later questions.

Working conditions

If the students' working conditions are not somewhat comparable to industry working conditions, the level of realism can suffer. For example, if most workers have computers but most students do not, there would be problems generalizing from the student sample to the work-place sample due to differences in work methods.

The emphasis in the A/E/C PBL course on distributed work and the use of cutting edge commercial technology, not all of which are used by practitioners, made the A/E/C PBL teams reflect the working conditions of the future more so than those of today. Each A/E/C PBL team included at least one member who was not collocated, which is very common in the construction industry. After the two-day project launch, teams did not meet again face-to-face until the final presentation four months later. Distributed team members communicated mainly through computer-based Internet applications. Internet meeting applications allowed audio and video communication and desktop file sharing. Internet message applications allowed asynchronous message transfer between two or more parties. An Internet application developed for the course facilitated the posting and retrieval of messages and files. Collocated team members used face-to-face meetings as needed. Whereas many workers belong to distributed teams and most workers have access to Internet technology, not all industry workers choose to use the full range of advanced communications technologies provided to the students. Therefore, the A/E/C PBL environment was very realistic in the access it gave students to communication tools, but it was slightly unrealistic in the wide variety of advanced tools available compared to current work resources.

PBL work group composition attributes

The social setting of the PBL environment can contribute to the realism of the experience and it is very important when work-group interactions are the focus of the study. The following work group composition attributes influence the realism of the PBL environment.

Role-play simulation

If the PBL program instructions do not suggest work-related roles, the students may solve the problem or complete the project without assistance to adopt a work-related identity. These students will be less likely to replicate interactions and behaviors found in an industry work place. The adoption of roles in a PBL course enhances the realism of the experience for the learner as the different 'actors' provide the student with cues to appropriate behavior. For example, in a Geographic Information System PBL environment [5, p. 332] the student's task was to be a group of consultants designing a pilot project to introduce a GIS into the department of the local borough council. Adopting the role of consultant, and interaction with the local council made the experience more realistic for the students than, for example, writing a report based upon a case study.

The A/E/C PBL project was enacted as a role-play simulation with different people fulfilling different roles. The graduate students were 'journeymen' assisted by undergraduate 'apprentices' and mentored by the 'Masters', globally distributed professionals working in each discipline. The 'Owner', usually a past student of the course, communicated the client's specifications and requirements to the group. The group had to work within the client's specifications or contact the Owner to request a change. The varied nature of the group, with different professions (architect, structural engineer and construction manager), different roles (owner, worker) and different levels of expertise (apprentice, journeyman or Master) more closely replicated the complex social relationships experienced in a work environment than the typical educational environment.

This use of specialized roles made the A/E/C PBL environment more realistic and comparable to an industry workgroup setting, where individuals have different levels of skill and different roles. The use of different roles, such as 'Owner', provided the A/E/C PBL participants with social cues that increased the realism of their experience. For example, when the Owner asks why the proposed solution does not meet the design specifications the student has a more realistic experience than when the teacher asks why the assignment was late. In the study of trust, we noticed that students were behaving true to their roles when performing their tasks.

Individual versus team projects

If the research study focuses upon work group interactions, the PBL environment should be organized around a team-based project. For example, some PBL programs engage students individually; others revolve around group problems or projects that replicate the social environment of the work place. The research objectives should indicate the suitability of either an individual or group problem.

The A/E/C PBL project was based on a group activity. One student could not do the project alone, partly because there was too much work but mainly because it required the specialized skills of an architect, structural engineer and construction manager. Since our research objective was to study trust relationships between different disciplines, the team setting was appropriate.

Education and work experience

Students with little education or work experience do not provide as good a sample as those who are more similar to the typical industry worker. The closer the student's education is to those working in the industry and the more work experience of the students the more realistic will be their PBL experience. For example, a PBL environment populated with seniors is more comparable to an industry group that has, on average, undergraduate qualifications, than would be a class of freshmen students.

On average, the A/E/C PBL students had taken 12 courses with a focus in their primary discipline, architecture, structural engineering, or construction management. The students also had an average of 8 months full-time work experience in their discipline domain. Because this was a capstone course in a Masters degree program, the students had as much education and experience as a typical entry-level worker in the industry.

The high level of education of our sample meant that, like professionals in industry, the students had already adopted the professional identities and culture of their chosen discipline. Just as they will encounter specialists in the workplace, they had to act as specialists and interact with other specialists, thus increasing the realism of the experience. These factors were important to our study of trust in cross-functional teams

Cross-disciplinary team composition

PBL environments that have students with similar educational backgrounds, do not replicate the typical heterogeneity of many industry teams. For example, a PBL course in product design is likely to contain students who have completed certain prerequisite courses in mechanical engineering, whereas a product design team in industry is also likely to contain specialists in manufacturing production and marketing.

The A/E/C PBL teams were cross-disciplinary, composed of masters students drawn from United States, European and Asian universities in three disciplines—architecture (A), engineering (E), and construction management (C). The cross-functional nature of these teams increased the level of realism by providing each participant with a specialized professional role, more accurately replicating the heterogeneity of industry teams.

PEDAGOGIC ADVANTAGES AND CONSTRAINTS

Using a PBL class as a research data source can provide valuable inputs to course development that could benefit current and future students. Involvement in research increases the organization's level of prior knowledge about the topic and consequently it's absorptive capacity, the 'ability to recognize the value of new, external information, assimilate it, and apply it' [18, p. 128]. This process should apply to educational institutions and PBL just as it does to commercial organizations.

For example, if the research objective is descriptive, the educators will have access to information about student interactions that is likely to be useful in designing course improvements. If the research project aims to test a new work tool or procedure, future students will benefit from the knowledge gained about the usefulness of the innovation.

The research conducted with the A/E/C PBL has lead to numerous course improvements and tools, some of which are so promising as to be patented and commercialized by Stanford University.

The general goal of problem-based learning is to provide students with an opportunity for experiential learning in a supported environment that will facilitate the transfer of knowledge from the educational context to the professional context [19]. With this objective, any increase in the realism of the work context or the workgroup composition would usually facilitate the learning experience, as long as a sufficient level of student support was maintained. But, to increase realism by withdrawing educational support would create a conflict with the pedagogic goals in most cases. Except for such examples, in general the researchers' and the educator's goals are both better achieved when the realism of the PBL experience is increased.

In contrast, there could be a conflict between pedagogic and research goals when researchers exercise their control to create experimental interventions. For example, in the A/E/C PBL research project, we considered dividing the class into a control group and experimental group and providing extra training to the experimental group to see if that would affect their level of trust and performance. We decided not to use that research design because it would be difficult at the end of the course to readjust the grades to remove the presumed advantage provided to half of the students by the additional training, and the other half of the students would miss out on the benefits of the training. Ultimately, we felt that it was not equitable to provide advantages to some students and not to others. Adopting this standard constrains the use of experimental interventions in a PBL environment. Such limitations are not unusual in any research environment, since 'Human Subjects' standards tightly regulate the way that subjects can be treated in research studies.

PBL data sources have Human Subjects considerations in addition to those normally considered for a research project by virtue of the fact that the research subjects are students and their grade could affect their future work opportunities. Therefore, the research design cannot be allowed to interfere with the learning opportunities of the course or 'the level playing field' upon which the assessment and evaluation of the student's performance are based. The research design should not interfere with a student's ability to compete for a grade on an equal basis with other students. Therefore the research design cannot unduly advantage or disadvantage any students. For example, a research design that provides an experimental stimulus to the experimental group of students but not the control group must be considered very carefully to ensure it does not advantage or disadvantage the experimental group. It is difficult to guarantee fair grading when one group of students has a more challenging task or fewer resources.

DISCUSSION AND CONTRIBUTIONS

This paper shows that, depending upon the population of interest a PBL data source can provide a natural, semi-natural or experimental setting. In the case of a work-related study, a PBL data source provides an artificial setting that can be more realistic than a social science laboratory experiment, and the PBL can provide an opportunity for longitudinal studies, but with some restrictions on the level of experimental intervention available.

When evaluating a PBL as a data source the greater the realism of the work context and the workgroup composition, the more realistic will be the PBL and the better it rates as a data source. Indeed, when relevant and complex project-based problems are tackled in industry-like work conditions over longer time frames the PBL can be very realistic. Similarly, when participants with industry-level education and experience enact specialized roles in different disciplines and interact with the professional community the realism of the PBL can be very high.

Organizational features of the PBL can also contribute to the quality of the research design, such as random allocation of subjects to groups, similar group projects, continuity from year to year and research techniques appropriate to the potential sample sizes.

The fact that PBL projects can be enacted over a longer time frame than a typical synthetic experiment—in our case study 5 months—makes PBL a potential research data source for longitudinal studies. In addition, since the PBL class may be repeated, it provides an opportunity to develop and test models in an iterative process of building, testing, revising and retesting.

LIMITATIONS AND FUTURE RESEARCH

Despite the level of realism achieved, PBL is an artificial replication of a work-place data source, and the question of generalization to the work population remains.

This highlights the need for research studies to compare the results from matched studies differing only in their use of PBL versus workplace data sources. Comparative research to benchmark the potential generalizability from the PBL data source to the workplace populations would be helpful.

In the case of our A/E/C PBL case study, we found inconclusive relationships between the situational variables, risk and reward, and our dependent variable, trust. One of the strategies of any educational environment is the reduction of risk to encourage the student to experiment and learn. In an industry setting, the risks are real. These strongly motivate, and are highly relevant to, trust. Therefore, we believe that the relationship between the variables risk, reward and trust would be much clearer in an industry sample.

CONCLUSION

As the use of problem-based learning increases, more variation in PBL design is likely to occur and more researchers will take advantage of the opportunities PBL environments offer as a research data source. This paper uses a case study of a research project investigating trust in cross-functional, global teams to illustrate key characteristics of a PBL as a research data source. The case study research project, Trust in Cross-functional Global Teams, used Stanford University's Civil Engineering PBL as a work-related data source. We propose that the more realistic the work context and workgroup composition, the better the data source as a proxy for an industry sample. PBL course design can also contribute to the research design by using random assignment to teams, annual continuity, and research techniques appropriate to the sample size.

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REFERENCES

1. R. Fruchter, Architecture/engineering/construction teamwork: a collaborative design and learning space, *ASCE Journal of Computing in Civil Engineering*, **13**(4), 1999, pp. 261–270.
2. M. A. Copland, Problem-based learning and prospective principals' problem-framing ability, *Educational Administration Quarterly*, **36**(4), 2000, pp. 585–607.
3. R. Fruchter and K. Emery, Teamwork: assessing cross-disciplinary learning, *Computer Support for Collaborative Learning Conference, 1999*, pp. 166–173.
4. D. M. Cannon and L. J. Leifer, Product-based learning in an overseas study program: the ME 110K course, *Int. J. Eng. Educ.*, **17**(4 & 5), 2001 pp. 410–415.
5. D. Livingstone and K. Lynch, Group project work and student-centered active learning: two different experiences, *Studies in Higher Education*, **25**(3), 2000, pp. 325–345.
6. P. Resnick, Learning in school and out: the 1987 AERA presidential address, *Educational Researcher*, **16**, 1987, pp. 13–20.
7. C. S. Iacono and S. Weisband, Developing trust in virtual teams, *Proc. 30th Annual Hawaii Int. Conf. on System Sciences Hawaii, 1997.*
8. D. Macdonald and G. Isaacs, Developing a professional identity through problem-based learning, *Teaching Education*, **12**(3), 2001, pp. 315–333.
9. E. M. Bridges, *Problem Based Learning for Administrators*, ERIC Clearinghouse on Educational Management, University of Oregon (1992).
10. A. Garvin and S. Carrington, Student-authored hypermedia in veterinary anatomy: teaching and learning outcomes of group project work, *British J. Educational Technology*, **28**(3), 1997, pp. 191–198.
11. R. Zolin, P. Hinds, R. Fruchter and R. Levitt, Trust in cross-functional global teams, *Organization Science Special Issue 'Trust in an Organizational Context'*, Milan, Italy, 2001, pp. 105–152.
12. N. Blaike, *Designing Social Research*, Malden, MA: Blackwell Publishers, Inc.(2000).
13. E. Babbie, *Survey Research Methods*, Belmont, CA: Wadsworth, Inc. (1988).
14. J. M. Feldman and J. G. Lynch, Jr., Self-generated validity and other effects of measurement on belief, attitude, intention and behavior, *J. Applied Psychology*, **73**(3), 1988, pp. 421–435.
15. L. C. Hamilton, *Regression with Graphics: a Second Course in Applied Statistics*, Belmont, Canada: Duxbury Press (1992).
16. R. Axelrod, *The Evolution of Cooperation*, New York, NY: Basic Books (1984).
17. M. Segers and F. Dochy, New assessment forms in problem-based learning: the value-added of the student's perspective, *Studies in Higher Education*, **26**(3), 2001, pp. 327–343.
18. W. M. Cohen and D. A. Levinthal, Absorptive capacity: a new perspective on learning and innovation, *Administrative Science Quarterly*, **35**, 1990, pp. 128–152.

19. P. C. Candy and R. G. Crebert, Ivory tower to concrete jungle: The difficult transition from the academy to the workplace as learning environments. *J. Higher Education*, **62**(5), 1991, pp. 570–592.

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