# Statistical Techniques for Project-based Learning

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**Abstract—Although present for a long time, project-based learning is still the very focus of researchers because of its potential to improve the learning process. New technologies provide opportunities for a better understanding of the data generated by the learning process. This literature review searches for statistical techniques used in the field of project-based learning and classifies them in line with common classifications found in the field of statistics. The goal is to identify the most common statistical techniques used in the field and explain the way they are applied in the research. The results show that the most often statistical techniques are descriptive statistics and inferential statistics, followed by factor analysis, regression analysis, correlation, and social network analysis. This result arises from the type of research design, which is in most cases quasi-experimental, where researchers try to measure the influence of project-based learning on different dimensions of learning outcomes. This kind of research design usually employs descriptive statistics as a preliminary step, followed by statistical tests.**

**Keywords - statistical analysis, inferential statistics, quasi-experimental research design**

## I. INTRODUCTION

Project-based learning is a form of learning by doing in which the student is at the center of the learning process acquiring deeper knowledge through active exploration of real-world challenges [1]. This approach helps motivate students as they play an active role, collaborating with other students and instructors in producing artifacts [2]. Various forms of computer software and other cognitive tools can significantly amplify and extend what students can learn [1].

Although the beginnings of the scientific field date to the early 20th century, project-based learning is still the focus of researchers because of its potential to improve the learning process. The modern approach includes quasi-experiments where the outcomes from the project-based learning process are measured against the classical or some other approach. These outcomes can be classified as [3]:

- cognitive outcomes which include knowledge and strategies,
- affective outcomes like student's perception of benefits and experiences with project-based learning,
- behavioral outcomes which relate to various kinds of skills and student engagement in the learning process and
- artifact performance, i.e., measurable characteristics of physical objects, documents, and multimedia created as a result of the learning process.

Different types of instruments can be used for the measurement of these outcomes. The most frequently used are self-reported questionaries, rubrics, tests, interviews, observation, self-reflection journals, and artifacts. Especially useful sources of data are software logs where computer technologies are used as a scaffolding tool. Software logs contain data about the contents, timing, and frequency of students' activities and enable the discovery of patterns in students' behavior. This additional information can help teachers and researchers improve curricula in the next iteration by better understanding students' strategies, interests, and engagement [3].

Data obtained from the learning process can be qualitative and quantitative. Which type will prevail in the research depends a lot on the goals and the design of the research. Combining both types can sometimes reveal more information about the learning process. When computer software is included as a tool in the learning process, a huge amount of quantitative data can be generated, which can require complex and computationally demanding techniques for their processing. The development of statistical techniques and machine learning, backed with rising computing power provide tools for this processing.

The focus of this literature review is on quantitative techniques used to analyze the data originating from the project-based learning field. The goal is to find out the quantitative statistical techniques most frequently used in project-based learning and describe the typical way they are applied. With this goal in mind, two research questions are formulated:

Q1: Which quantitative statistical techniques are the most often used in the field of project-based learning?

Q2: In what way are the statistical techniques applied in the field of project-based learning?

The remainder of the paper is structured as follows: The methodology section outlines the methodological approach in this literature review. Chapter Results and Im-

plications briefly describe the quantitative statistical techniques found in the literature and the context in which they are applied. Finally, the chapters Discussion and Conclusion give an overview of the results of the research, point out the main findings and limitations of the research, and propose the future direction of the research.

## II. METHODOLOGY

Concerning the goal and the type of data collected, this literature review is descriptive and qualitative. The literature reviewed is collected from the Web of Science and Google Scholar databases of academic articles. Included are peer-reviewed articles published in scientific journals, and papers published in conference proceedings in the period 2018 through 2022 without restrictions on the research design. Literature reviews are excluded from the review. Only the papers that relate to project-based learning which include quantitative statistical processing of data are considered relevant. Papers whose entire text was not available were excluded from the review.

The initial search was made on April 10th, 2023, in English. Both databases were searched for the exact phrase "project-based learning". Since the search returned a large number of hits, results are sorted by relevance, and the first 30 hits from each database are taken to the second round of elimination. The papers were selected based on the abstract. In the next step, the full text of articles that were found relevant was carefully analyzed from the viewpoint of the statistical methods used for data processing, and the final list was made. It is comprised of 43 articles on project-based learning that use quantitative statistical techniques. They make the foundation for the discussion and conclusion.

## III. RESULTS AND IMPLICATIONS

Table 1 shows the frequencies of quantitative statistical techniques found in the sample. Techniques are grouped by common classifications found in the field of statistics.

*Table I. Statistical techniques in the sample*

| ***Statistical technique*** | ***Number of articles*** |
|---|---|
| Descriptive statistics | 34 |
| Inferential statistics | 29 |
| Factor analysis | 7 |
| Correlation | 6 |
| Regression | 6 |
| Social network analysis | 1 |

In the following subsections, each technique and its usage are briefly described. Where appropriate, the examples from the literature are briefed in the context of the research.

### *A. Descriptive statistics*

A set of techniques designed to describe and sum the data is called descriptive statistics [4]. It is a common term that includes the measures of central tendencies, measures of dispersion, and the shape of the distribution. It merely reports measured data, without producing a prediction or conclusion about the population [5].

Descriptive statistics is one of the major techniques used for monitoring and analyzing learning data. Usually, the researcher starts with some kind of descriptive statistics technique to get a better understanding of the data. For that reason, it is included in almost every quantitative research, regardless of its design.

Applications of descriptive statistics in the field of project-based learning include monitoring students' activity and engagement over time, inspecting online behavior, and providing feedback [6]. It enables the identification of the extreme values in the data which can help identify students at risk [7].

In the sample of analyzed articles, mean and standard deviation are the most often reported measures, followed by a table of frequencies, percentages and percentile ranks, range, minimum and maximum. Where the mean is not an appropriate measure because of the data type used in an analysis, the median is used instead. Major descriptives can also be presented as boxplots, as in [8]. In [9] and [10] authors used skewness and kurtosis for the description of the shape of the distribution. Cronbach's Alpha, CR (composite reliability), and AVE (average variance extracted) are often classified under descriptive statistics. They are used to measure some characteristics of the construct, like the reliability of an instrument used for data collection or its discriminant validity. These measures are often reported when research includes questionary [10], [11], [12], [13], [14] [15], [16], [17], [18].

### *B. Inferential statistics*

Inferential statistics is a set of mathematical techniques based on a probability theory and the logic of hypothesis testing that enable researchers to test hypotheses, quantify covariances between variables, or identify causal relations based on the analysis of a sample [4]. This kind of analysis aims to provide valid conclusions about the population characteristics from which the sample was drawn. Inferential statistics should provide an answer to the question if the sample comes from a known population, or the two or more samples come from the same population. In addition to the estimate of parameters, valid inferential statistical procedures must provide information about the precision of this estimate [19].

The choice of an appropriate statistical test depends on the goals of the analysis, the type of data, the number of groups that are compared, and the relationship between the groups [5]. The basic classification is parametric and

non-parametric, based on the type of data distribution. Tests based on the normal distribution are called parametric, while others are considered non-parametric. Depending on the goals of the analysis, the researcher can test for the differences or the correlation between the groups. In the remainder of this section, different tests of difference will be explained, while tests of correlation will be presented in the subsequent sections.

The most often test used in the sample of articles is the t-test. It is used when the means of two groups are compared to establish if they come from the same population. T-tests can exist in two forms: t-test for independent samples and paired t-test. When the appearance of a student in one sample excludes the possibility of their appearance in other samples, a t-test for independent samples is used [9], [14], [20], [21], [22], [23], [24], [25]. This is the situation where, for example, students in the experimental group are compared to students in the control group. On the contrary, if both samples are consisted of the same persons, then paired t-test is used [12], [13], [16], [20], [21], [22], [25], [26], [27], [28], [29], [30], [31]. This is the case where there are repeated measures of the same group of students, i.e., when pre-test and post-test are done. Where data does not comply with the requirements of the t-test, the Mann-Whitney test is used for independent samples [8], [18], [32] and Wilcoxon's test [33] is used for paired samples as non-parametric alternatives to the t-test. When more than two groups are compared, one-way [14], [34], [35] or two-way [36] ANOVA (analysis of variance) is used, depending on the number of variables observed. If the samples are paired, then ANOVA for paired samples is the appropriate statistical technique [11], [37]. Non-parametric alternative to ANOVA is Kurskal-Wallis test [18]. To provide information about the main and interaction effects controlling for the effects of other variables which co-variate with the dependent variable, ANCOVA (analysis of covariance) is used in [12], [38], [39]. These statistical tests rely on statistical significance. Since statistical significance doesn't imply practical significance, some researchers report the effect size in addition [13], [18], [27], [31], [34].

### *C. Correlation*

Correlation analysis is conducted to get the answer to the question if there is a relationship between two variables, in which direction the relation goes, and how strong it is. Relation in this context describes the tendency of two variables to vary consistently [5]. The most popular measure of the correlation is the correlation coefficient [13], [40]. Where there are multiple variables whose relations are examined in pairs, correlation coefficients are usually presented in the form of a matrix [16], [17], [41].

Another way to examine and present the existence of a correlation between two variables is a scatter plot [8]. A scatter plot can be very useful in finding out the relationships which are not linear. Usually, it complements the correlation coefficient.

### *D. Regression*

Regression is a set of statistical procedures built around the concept of correlation which permit the researcher to use information about one or more variables to predict the value of one or more other variables. By enabling the inspection of the relationship between multiple variables at the same time, regression analysis overcomes the shortcomings of the correlation coefficient [42].

Regression analysis allows researchers to make models of different complexity, depending on the research goals. Multiple linear regression is used to predict the value of a dependent variable using multiple independent variables which presumably are in a relationship with the dependent variable in [11], [43], [44]. Hierarchical regression applied in [16] and [17] is the type of regression where independent variables are entered in steps based on a theoretical framework. Multilevel linear regression allows grouping the observations in multiple levels and is applied in [45].

### *E. Factor analysis*

In this section, the use of PCA (principal component analysis), EFA (exploratory factor analysis), and SEM (structural equations modeling) are presented. Although they significantly differ in many aspects, common for all these statistical techniques is that they allow for exploring the underlying structure of data.

PCA is aimed to extract information from the variance-covariance matrix in such a way that a group of random variables is reduced to a smaller group of random variables that reflect the original structure [42]. It is used in [37] and [44] to reduce the number of variables before the main analysis.

EFA uses PCA to discover the hidden structures laying in the background of covariances between variables. A set of related variables is transformed into a set of unrelated variables called factors or components, to get a relatively small number of variables that explain a significant portion of the original variance. The researcher must consider the theoretical framework when defining underlying factors [42]. In [13] and [45] authors applied exploratory factor analysis and then used the obtained factors in the regression and correlation analysis that follows.

SEM is a family of statistical techniques used for modeling complex relations between measured and latent variables. They include elements of regression and factor analysis providing more freedom for researchers to explore complex models. Within SEM family, path analysis was applied in [46] and [15], while PLS (partial least square) was applied in [10].

*F. Social Network Analysis*

SNA (social network analysis) is a tool for exploring relations between individuals or organizations. A social network is looked at as a graph made of a series of nodes each representing the actor and relations between them. To understand network structure and the patterns of the actor's behavior, a set of characteristics is examined. The most important are the degree of centrality, closeness and betweenness of nodes, density, and connectivity of the network [6].

Using SNA researchers can gain insight into the broader picture of interactions and dynamics of the participants in the project. On the group level, it is possible to discover the patterns of interaction between students and teachers, while on the individual level, it makes it possible to quantify the role of each participant in the network [47]. In [48] authors used SNA to investigate how it can lead to improvements in the learning process. On the individual level, they monitored three SNA constructs for each participant: the level of interactivity, role and position in the information exchange, and the role in collaboration. On the group level, they monitored interactivity and group cohesion.

## IV. DISCUSSION

Based on a literature review, statistical techniques used in project-based learning are identified and grouped in a way common in the field of statistics. Every technique has its peculiarities and assumptions for usage which emphasize the importance of using the appropriate technique for the goal and design of research.

One statistical technique alone rarely can answer the research questions and hence they are usually combined. Descriptive statistics is usually the first step in every analysis because it gives the basic information about the data which can direct further research. It is usually coupled with data visualization, which makes complex patterns easier to grasp.

The most common research design in the sample is quasi-experimental design. Students are separated into two or more groups. Those who belong to the experimental group get treatment in the form of project-based learning, while others work in a classical way. Measurements are usually done at the beginning of the project and after the project is finished. This way it is possible to measure the advancement in the outcome independently of the treatment, as well as compare experimental and control groups to test the effect of the treatment. Such a design greatly defines the statistical techniques used. In typical research, inferential statistics are used. It is recommended to report the effect size as well as the result of the statistical test [4].

When searching for differences between groups of students and only two groups are examined researchers apply t-test for independent samples and paired t-test. If there are more than two groups, then depending on the number of variables and their relationship one-way, two-way ANOVA or ANCOVA are used.

When the goal of the research is to find the level of influence that a variable exerts on the outcome of the learning, then correlation or regression analysis is applied. In addition, these techniques provide information for predicting outcomes and performing statistical tests at the same time. Regression analysis provides a way to put in relation more than two variables, while path analysis is used if a research design is even more complex.

In both cases, PCA and EFA are used to reduce the number of variables. SNA is useful for researching the structure and dynamics of the group.

Systematization of statistical methods made in this paper should provide easier comprehension of the methods for studying the effects of project-based learning on learning outcomes. A short description of statistical techniques in the language of applied statistics should give the researcher better insight into the "technical" part of the research and facilitate the understanding of non-technical researchers.

Although they are very useful in the exploration of the characteristics of the phenomenon under examination, quantitative statistical methods are not almighty. Quantitative methods can point out trends, correlations, groups, and structures in the data, but it is usually useful to complement them with qualitative methods which provide additional information and can help find out the causes of such results. [6].

## V. CONCLUSION

The literature review presented in this paper grouped numerous statistical methods and techniques used in research of project-based learning into six groups. Based on the presented, the answers to the research questions follows:

Q1: Which quantitative statistical techniques are the most often used in the field of project-based learning?

The most often used statistical techniques in the field of project-based learning are descriptive statistics, inferential statistics, factorial analysis, regression, correlation, and social network analysis.

Q2: In what way are the statistical techniques applied in the field of project-based learning?

Descriptive statistics describe the data and are used as a preliminary step that provides an overview of data. The research design determines the techniques used. Since most researchers use a quasi-experimental design aiming to identify the effect of the treatment, the technique of choice falls to the inferential statistics group of techniques. Within this group, the most common are t-tests and analysis of variance. Exploratory factor analysis is usually used to

reduce the number of variables. Where the research design is more complex, SEM is used, while SNA is used for discovering group structure and dynamics.

The limitation of this literature review relates to the relatively small sample of papers that are analyzed, which can lead to overemphasizing some techniques to the detriment of others. In the future, a more comprehensive review can include a larger sample. Also, future research can provide more details by focusing on a particular area of statistical techniques used with the most frequent research design.

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