Impact of smart classrooms in higher education on academic performance: a meta-analysis

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Abstract

Rationale of Study – With the development of information and communication technologies, colleges and universities worldwide have set up smart classrooms. This study aims to quantify the driving factors influencing student academic performance in a smart classroom environment.

Methodology – A meta-analysis method is used to quantitatively analyse smart classrooms' impact on higher education students' academic performance, covering seven courses, such as foreign languages and computers, and 15 papers from four countries. The label encoding scheme is used to convert the categorical variables into numerical variables, and the linear regression model is constructed to analyse the influence of each variable on students' academic performance.

Findings – The results show that smart classrooms positively impact the academic performance of higher education students with an impact value of 1.18, and the impact is more pronounced for operational courses such as dentistry and computer science.

Implications – A smart classroom environment dramatically improves students' learning effect, which is significant to students' autonomous learning.

Originality – This paper is based on an original study on the impact of smart classrooms in higher education in four countries.

Keywords

Education management, statistical analysis, data information, linear regression

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1 Introduction

Most of the classroom teaching in undergraduate colleges and universities is still based on the traditional indoctrination method; teachers' teaching is the main focus, and students' learning is supplementary. This way of teaching has played an essential role in reforming and improving teaching quality in universities. However, under the background of deep integration of information technology and classroom teaching, the drawbacks of traditional classroom teaching method gradually appear, such as less interaction between teachers and students, passive learning of students, lack of seminars and lack of innovation, and the inability to collect teaching data in a large amount and quickly under the big data environment. These drawbacks seriously restrict the development of contemporary information-based teaching. With the development of information technology, the deep integration of information technology and education, coupled with the concept of "smart earth", the derivation of smart classrooms. Domestic and foreign schools such as the University of California, the University of Toronto, Tsinghua University, East China Normal University, and Northwest Agriculture and Forestry University have built smart classrooms to improve the quality of education and teaching（Cao, 2017; Fan, 2015）. Since the 1990s, countries worldwide have built smart classrooms, especially in recent years. Search in Web of Science and CNKI indicated that the pace of the construction of smart classrooms has accelerated, and the related research literature on smart classrooms has increased rapidly (Figure 1). The construction of smart classrooms in China started late, starting around 2010. After more than a decade of rapid development, the volume of relevant literature has proliferated, reaching the highest level in nearly a decade in 2020.

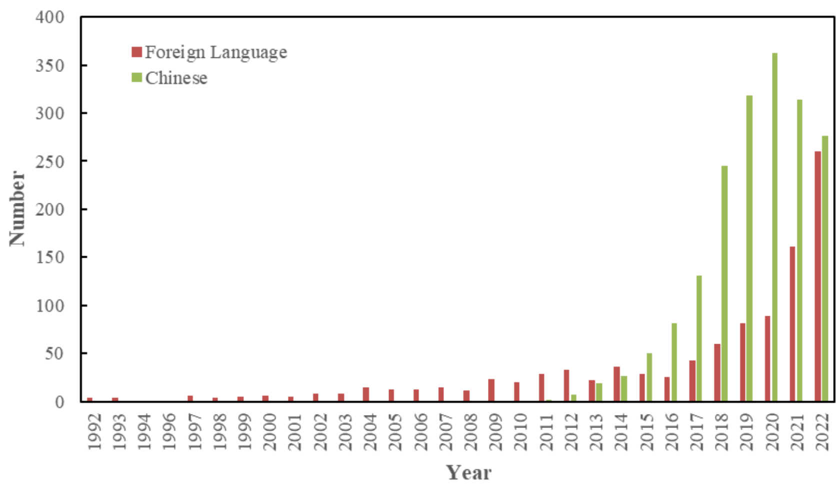

Figure 1: Trends in the number of literature related to smart classrooms

At the same time, the topics related to smart classrooms were analysed, including education, computer vision, management, telecommunications, language, security systems, social psychology, distance learning, design and manufacturing (Figure 2). It is not difficult to find that almost half of the research topics are related to "education research", followed by "computer vision and graphics", "human-computer interaction", "robotics", and other topics focusing on technology. The impact of smart classrooms on academic performance is of great significance for education and teaching.

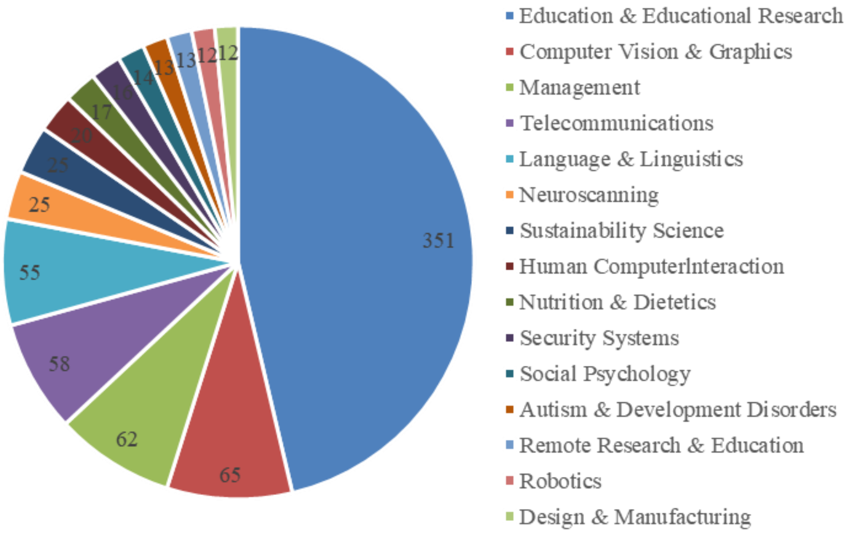

Figure 2: Distribution of topics related to smart classroom research

Smart classrooms have features such as classroom interaction, situational awareness, and easy access to learning resources (Huang et al., 2012). At the technical level, smart classrooms mainly consist of hardware and software devices. Hardware devices contain tables, chairs, whiteboards, and video capture devices, and software devices mainly contain software systems that support the operation of hardware. At the teaching level, smart classrooms have developed different teaching modes, such as flipped classrooms, inquiry teaching, and hybrid classrooms. Unlike traditional teaching methods, in the smart classroom environment, teachers use classroom interaction tools to guide students' independent learning, provide timely feedback on students' questions, and stimulate students' learning initiatives (Al-Qirim, 2016; Jun-Feng, 2016). MacLeod et al. (2018) developed a tool containing 40 items in the context of higher education and measured students' preferences for the smart classroom learning environment in a smart classroom environment. Selim (2020) used an innovation theory model to investigate the main drivers that influence the functionality of smart classrooms. Zhaon(2022) constructed a university smart classroom based on face recognition technology in an IoT environment attendance management system, which can accurately record and identify students entering and leaving the classroom late arrival and early departure, absenteeism, and substitute classes. However, the system is susceptible to the influence of ambient light, students' sitting posture, and expressions and cannot be recognised. Xiaohua (2021) studied the application of smart classrooms in college English and found that students' satisfaction with the smart classroom was above 80%. Yue (2020) studied the influence of elements (images, videos, animations) in the smart classroom on moral education teaching in colleges and universities.

Dahong (2020) studied the application of a smart classroom rain classroom in a computer landscape design course, which can better stimulate students' learning interest compared with a traditional classroom. Zhan (2021) studied the impact of smart classrooms on teacher-student interaction by comparing the behavioural sequences of smart classrooms and traditional multimedia classrooms. Chen (2021) reviewed smart learning research areas, research themes, and the evolution process in detail. Zhang (2020) used a meta-analytic approach to explore classroom instruction from the cognitive, affective, and skill domains in a smart classroom environment. Zhiyan (2022) used a meta-analytic approach to analyse the overall impact of smart classrooms on learning outcomes for the full range of learning stages. The above studies mainly focus on the application of smart classrooms in the classrooms of universities and schools, and the research on the classroom learning of college students in the smart classroom environment is fragmented and lacks a quantitative analysis of the impact of smart classrooms on the learning performance of college students. Therefore, this study aims to use the meta-analysis method to quantitatively analyse the driving factors affecting students' academic performance in the smart classroom environment.

2 Methodology

2.1 Data collection

This study used Web of Science and CNKI, an online database of peer-reviewed journals, to conduct a full-text search of research papers between 2010 and 2022, during which smart classrooms developed rapidly. The literature search was conducted using the keywords "smart classroom", "intelligent classroom", and "learning achievement" or "score". The studies cited in the meta-analysis had to conform to the following principles to eliminate discrete data.

1. Both experimental and control groups must be included.

2. The subjects must be college students in higher education institutions.
3. The experiments must contain student learning outcomes (in percentages).
4. The indicators' mean, standard deviation or standard error, and sample size can be directly calculated or extracted.

Based on the above exclusion criteria, 15 articles that met the criteria of this study were selected from the 283 articles retrieved, and a meta-analysis method was used to quantitatively analyse the impact of smart classrooms on the academic performance of students in higher education institutions. To ensure the accuracy and reliability of the analysis results, the linear regression model was used to analyse the impact of each categorical variable on the indicators, and the meta-analysis results were combined to analyse the effect size of each variable quantitatively.

When the data of the selected study is displayed in graphical form only, the values are extracted using Get Data Graph Digitizer v. 2.25.

2.2 Data analysis

The Hedges' effect values were calculated in the meta-analysis, as shown below.

$$d = \frac{(X_e - X_c)}{S} \; J = \sqrt{\frac{(N_e - 1)S_e^2 + (N_c - 1)S_c^2}{N_e + N_c - 2}} \qquad (1)$$

Xe, *Xc* are the means of the experimental and control groups in an independent study, respectively; *Se*, *Sc* are the standard deviations of the experimental and control groups, respectively; and *Ne*, *Nc* are the sample sizes of the experimental and control groups.

$$J = 1 - \frac{3}{4(N_e + N_c - 2) - 1} \qquad (2)$$

Where *J* is the correction factor, and it will show a significant variance when the sample content is negligible.

The effect value variance is:

$$V_d = \frac{N_e + N_c}{N_e N_c} + \frac{d^2}{2(N_e + N_c)} \qquad (3)$$

All statistical analyses on meta-analysis calculations were performed using STATA software, widely used in the medical, ecological, and educational fields. The chi-square test (P) determines whether a fixed-effects or random-effects model is chosen for the weighted combination. If the chi-square test P > 0.1 (not significant, consistent with the chi-square assumption), multiple independent studies are considered homogeneous, and the fixed-effects model can be used to calculate their combined volume. If the chi-square test P≤0.1 (significant, not by the assumption of chi-square), the random-effects model can be selected, and then the effect size and 95% confidence interval can be calculated. If the 95% confidence interval does not overlap with 0, it indicates that the effect of the categorical factor on the indicator is statistically significant. 95% confidence intervals, when they do not overlap between subgroups, indicate that the mean effect sizes of the influencing factors are significantly different between subgroups.

Publication bias affects the results of meta-analysis, and Rosenthal (1979)suggested that the results are considered robust when Rosenthal's fail-safe number K (K represents the sample size of the effect size) value is much greater (Rosenberg, 2005).

2.3 Data classification

The variables in the database constructed for this study contain the type of journal, the region to which the study belongs, the category of the subject, the category of the course of study, and the indicator is student performance, calculated on a percentage scale. As shown in Table 1.

Table 1: Literature included in the meta-analysis

ID	References	Journal	Country	Object	Course	Sample (C/T)
1	(T Sevindik et al., 2010)	Telematics and Informatics	Turkey	Medical students	Professional Course	33/33
2	(Gao Ning et al., 2022)	Wireless Communications and Mobile Computing	China	Medical students	English Course	10/10
3	(Li Dahong et al., 2020)	Computer Applications in Engineering Education	China	Environmental design students	Computer	84/84
4	(Cao Feng et al., 2022)	Mobile Information Systems	China	Physical education student	Sports	160/160
5	(Ran Yan et al., 2022)	Scientific Programming	China	Vocational college students	Professional Course	42/42
6	(Nissreen Nugud Mergany et	BMC Medical Education	Sudan	Medical students	Dentistry	34/34

	al., 2021)					
7	(Sambit Dash et al., 2016)	Biochemistry and Molecular Biology Education	India	Medical students	Medicine	100/100
8	(Zhang Shuang et al., 2021)	Overseas English	China	Computer students	English Course	119/119
9	(Zhang Xuejia, 2021)	China Management Informationization	China	Vocational college students	Professional Course	54/53
10	(Wang Ying et al., 2021)	Journal of Bengbu Medical College	China	Medical students	Medicine	107/112
11	(Lv Jinyan et al., 2021)	Survey of Education	China	Medical students	Medicine	100/100
12	(Zhou Xuru, 2021)	Master Thesis of Henan Normal University	China	Educational students	Pedagogy	52/52
13	(Li Shushu, 2021)	Master Thesis of Chongqing Normal University	China	Computer students	Computer	37/45
14	(Yan Guiling, 2020)	Master Thesis of Shandong Institute of Physical Education	China	Environmental design students	Sports	30/30
15	(Ding Shifen, 2020)	Master Thesis of Chongqing Normal University	China	Computer students	Computer	66/61

2.4 Linear regression model

Linear regression is a statistical model that predicts the relationship between a continuous numerical variable (dependent variable) and one or more continuous or discrete variables (independent variable). The linear regression model assumes a linear relationship between the dependent variable and the independent variable, which can be expressed as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n . \qquad (4)$$

Where y is the dependent variable, $x_1, x_2, \ldots x_n$ are the independent variable, $\beta_0, \beta_1, \beta_2, \ldots \beta_n$ and are the parameters of the model?

4 Results and Discussion

3.1 Quantitative analysis of the impact of smart classrooms on students' performance

Meta-analysis of 15 kinds of literature revealed heterogeneity with I2>75%, so a random effects model was chosen. In Figure 3, the diamond in the middle of each study represents the study's effect size, and the bottom diamond represents the overall effect size of the study. In the studies comparing smart classrooms with traditional classrooms on students' academic performance, seven had minor positive effects, and six had strong positive effects with effect sizes above 1. Teaching and learning in smart classroom environments positively affects students' academic performance. The quantitative analysis of student learning achievement in the smart classroom environment in 15 higher education institutions showed that the smart classroom was more effective than the traditional classroom in improving the learning achievement of students in higher education institutions, with a total effect value of 1.18.

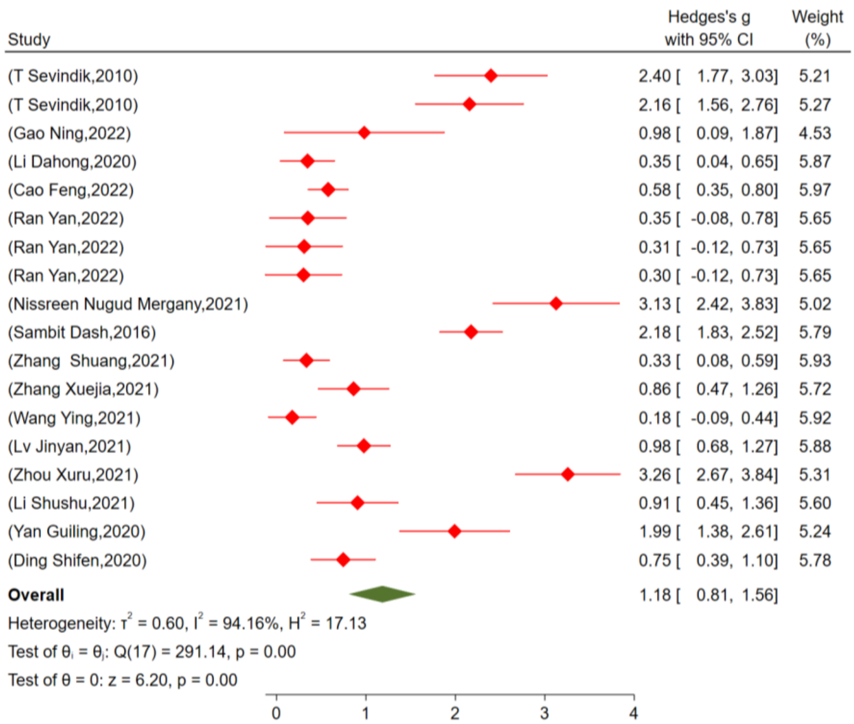

Figure 3: Overall weighted response of student achievement to smart classrooms

3.2 Subgroup analysis

Regional factors. As shown in Figure 4, the heterogeneity among countries is evident, among which Sudan has the largest mean effect size of 3.13, Turkey has 2.27, India has 2.18, and China has 0.82. The reasons for the differences are mainly the sample size, as there are fewer studies on the impact of smart classrooms on academic performance in higher education institutions, and the sample size in China is relatively large. Another reason is that some countries are in the initial stage of smart classroom construction, and the teaching methods in the smart classroom environment are relatively homogeneous. We should know that not all teaching methods in the smart classroom environment will necessarily improve students' performance, which is more prominent in China, where a variety of teaching methods have been introduced, such as rain classroom, flipped classroom, Umoja, interactive classroom, if they do not make full use of the convenient resources provided by the smart classroom and do not play the initiative of students' learning, the quality of students' learning will not be improved significantly. The quality of student learning is not apparent.

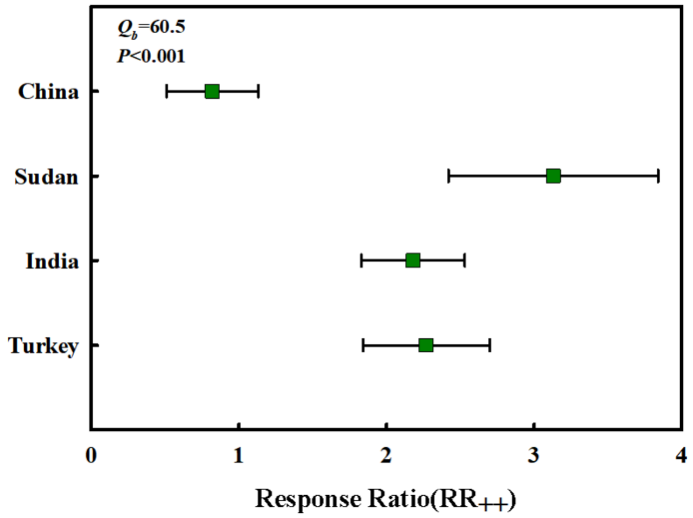

Figure 4: The impact of regional differences on student achievement in a smart classroom environment

Student object factors. As can be seen from Figure 5, the impact of smart classrooms on the learning performance of different categories of students also varies, with the lowest effect value of 0.46 for students in higher education institutions and relatively higher effect values for education and medical majors, on the one hand, because the sample size of education is smaller. On the other hand, because medical majors are more practical and operational, students can better draw knowledge through the convenient conditions provided by the smart classroom environment, such as through video, audio, and interactive and improve their practical operation skills.

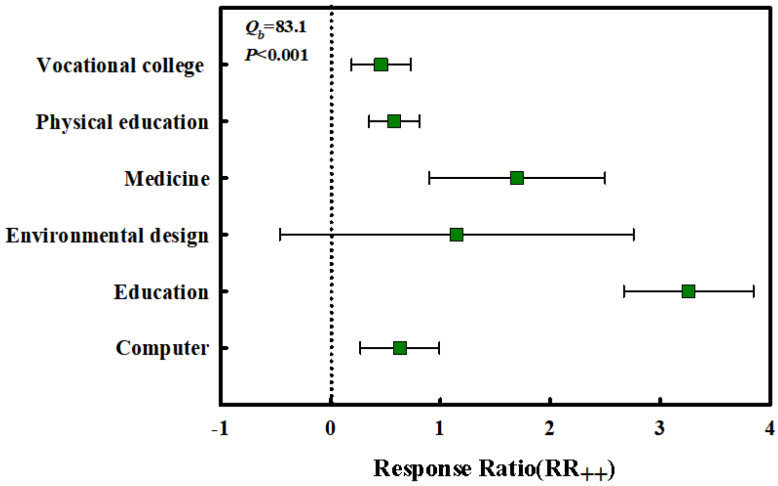

Figure 5: The influence of object categories on students' academic performance in a smart classroom environment

Course category factors. As shown in Figure 6, the differences between courses are also apparent, with lower effect values for introductory courses such as computer and English. Again, this indicates that in the smart classroom environment, the hands-on courses have a greater impact on students' learning outcomes because they are more intuitive.

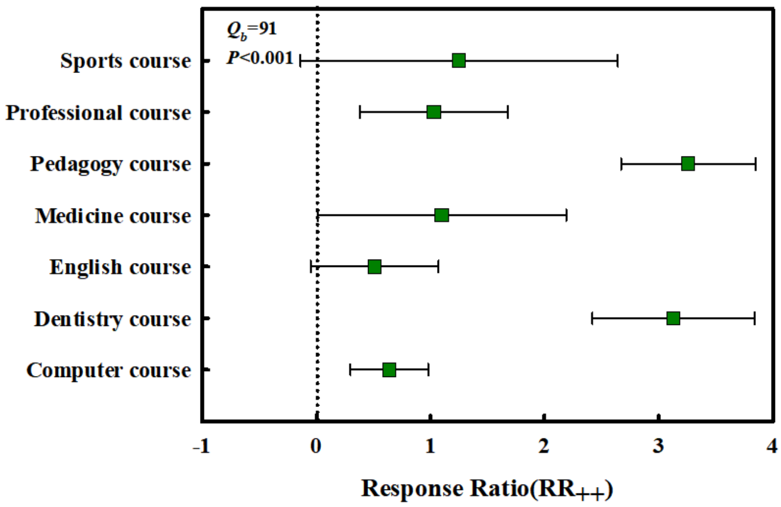

Figure 6: The impact of course categories on students' academic performance in a smart classroom environment

3.3 Publication bias analysis

In order to further evaluate the publication bias of the study, the concept of fail-safe coefficient was introduced. 95% of the studies reported non-significant results. To exclude possible publication bias, the minimum number of unpublished articles needed to overturn the results of the Meta-analysis could be calculated. The Fail-safe N of this study was calculated by applying Rosenthal's method using OPENMEE software(Gurevitch et al., 2018) as 2895, which is much greater than 5*15+10=85, i.e., a minimum of 2895 unpublished articles with the conclusion that smart classrooms hurt students' academic performance compared to traditional classrooms are required to overturn the Meta-analysis Therefore, the mean effect value of this study is considered solid and there is no significant publication bias.

3.4 Impact analysis of categorical variables

Since most of the variables (country, student object, course category) in this study are textual rather than numerical, Label Encoding small coding scheme was used to convert categorical variables into numerical variables. In this coding scheme, each classification was assigned a unique integer index, which was used to represent the value of the classification in the feature matrix. For example, suppose there was a categorical variable "country" with four categories: "China", "India", "Turkey", and "Sudan". In that case, LabelEncoding will generate a new feature matrix with four variables, where each variable was assigned a unique integer index; for example, it was 0 for China, 7 for India, 15 for Turkey, and 14 for Sudan, see Table 2.

Table 2: Change of variable

Categories	**Serial number**	**Variable of classification**	**Numerical value variable**
State	1	Turkey	15
	2	China	0
	3	Sudan	14
	4	India	7
Student object	5	Medical students	8
	6	Environmental design students	6
	7	Physical education students	11
	8	Vocational college students	16
	9	Computer students	2
	10	Educational students	4
Course category	11	Professional Course	12
	12	English course	5
	13	Computer course	1
	14	Sports course	13
	15	Dentistry course	3
	16	Medicine course	9
	17	Pedagogy course	10

Part of the code is shown in Figure 7.

```python
import numpy as np
from sklearn.preprocessing import LabelEncoder
# Create LabelEncoder object
le = LabelEncoder()
# Categorical variables were coded as integers.
encoded_variable = le.fit_transform(['China', 'India', 'Turkey', 'Sudan'])
print(encoded_variable)
```

Figure 7: A code that converts a categorical variable to an integer

The obtained linear regression model is:

$$y = -1.266x_1 + 0.094x_2 - 0.693x_3 \qquad (5)$$

Where y is the academic performance, x_1 is the state, x_2 is the student object, x_3 and is the course category?

The linear regression model shows that national factors account for the most significant proportion, followed by course categories, negatively correlated with student performance. China has the most significant impact on academic performance, while computer and dental courses have the most significant impact. The results of linear regression are the same as those of meta-analysis, but there are also differences. The same applies to operational courses such as dentistry and computer science, which significantly impact students' academic performance. The difference is that the results of linear regression show that China has the most significant impact on academic performance. In contrast, the meta-analysis shows that China has the most negligible impact on academic performance, while Sudan has the most significant impact. This may be due to the limited collection of literature and sample size, mainly due to the lack of relevant literature on the Sudan national smart classrooms, and caused the results to deviate.

If the number of replicates of the experiment is considered, the linear regression model is:

$$y = -1.11x_1 + 0.219x_2 - 0.78x_3 + 0.054x_4 . \qquad (6)$$

Where x_4 is the number of repetitions of the experiment?

It is not difficult to find that increasing the number of repetitions of the experiment has little impact on the correlation between other factors and grades, and the correlation coefficient of the number of repetitions of the experiment is the smallest, that is, the number of repetitions of the experiment has little impact on the research results.

The research results showed that the regional differences, course types, and object types all impact students' performance, and practical operation courses such as dentistry and computer courses significantly impact student performance. The above research results indicated that the teaching environment of smart classrooms could cultivate students' cooperative and communication abilities, autonomous learning, problem-solving, critical thinking, innovative thinking, and metacognitive abilities.

4 Conclusions

The analysis method was used to quantitatively analyze the influence of smart classroom environments in colleges and universities on students' academic performance, and the linear regression model was used to analyze the influence of categorical variables on students' academic performance. Through data statistics and information integration, the results of this study provide a theoretical reference for the construction of smart classrooms in colleges and universities. Therefore, in the later construction of smart classrooms, we can consider the construction of smart classrooms that are more suitable for the needs of the practical courses.

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