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*Research Article*

# Microscope Usability Evaluation Based on Fuzzy Analytic Hierarchy Process

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The basic position of microscope in experimental teaching is increasingly prominent, but there is still a big gap between its multidimensional index factors such as operation efficiency, effectiveness, and user satisfaction and the goal of teaching application. Based on the usability design theory, Kinovea video analysis software and ANSYS finite element analysis software were separately used to carry out user observation and product structure testing and analyze the multiple heterogeneous factors affecting the use of microscopes in teaching application scenarios and record usability data; the Fuzzy Analytic Hierarchy Process was utilized to summarize and analyze the usability data and construct a usability evaluation model of microscope. Under the guidance of the usability evaluation model, the microscope was optimized, and its usability was verified by Jack simulation and finite element analysis at last. The results show that: On the layer of operational efficiency, the usability index of intuitive operation and easy to learn of the microscope accounts for the largest weight. On the layer of effectiveness, the index of stable structural connection of the microscope has a larger weight; adjusting the material properties and product structure can effectively improve the stability of the microscope. On the layer of user satisfaction, the index of use comfortably of the microscope accounts for the largest weight, and the comfort of students' neck and other joints can be improved by optimizing the microscope's functional layout. This research provides an evaluation index reference and design optimization experience for the multiple heterogeneous factor-driven microscope usability design in teaching applications.

## 1. Introduction

Teaching equipment is the material basis of educational reform and development, and the microscope, as the basic teaching instrument of experiments, promotes the integration of the teaching and practice training of natural science theory. Among the sustainable development goals issued by the United Nations, the Quality Education Goals emphasized the significance of basic teaching equipment in promoting students' awareness of quality. The Curriculum Guidelines for Comprehensive Practical Activities in Primary and Secondary Schools issued by the Ministry of Education in 2017 put forward clear requirements for cultivating students' experimental observation ability. Proficiency in using teaching observation instruments such as microscopes is a basic skill that students need to master. The use of microscopes is a way to stimulate students' interest in scientific research and strengthen theoretical cognition. However, the usability of microscopes is quite different from its teaching application requirements. The use of microscopes fails to systematically consider multidimensional influencing factors other than single product function, making it difficult to operate, low in efficiency, and high in error rate for students who lack experience in using scientific research instruments. On the one hand, it leads students to spend more time on learning microscope operation and less gain in strengthening theoretical cognition through microscope observation; on the other hand it leads to high damage rate of existing microscope in the use process, which increases the microscope cost of teaching application. Starting from the teaching application scenarios of microscopes, analyzing the multiple heterogeneous factors that act together in the scenarios, this research conducted a usability evaluation research of microscope from the perspective of Fuzzy Analytic Hierarchy Process to guide the improvement of the teaching and application value of multiple heterogeneous factors-driven microscope, to better meet students' theoretical cognition and practical needs.

## 2. Literature Review

*2.1. Usability Research.* Usability refers to the extent to which a system supports a specified user in a particular environment to perform a specific task with effectiveness, efficiency, and satisfaction [1]. Usability studies originated from the application of personal computer products, which were born in the United States in the 1980s, by coordinating computer operating systems to make it easier for ordinary users to use high-tech products. In the late 1980s, researchers began to pay attention to prototype design and iterative evaluation of product development process and proposed to collect product information and usage data through product sample test to carry out usability evaluation of products, to provide a reference for product design principles [2]. Usability evaluation is a multifactor concept that involves ease of use, system effectiveness, user satisfaction, and objective-specific evaluations that relate these different levels of factors to the actual user environment and play an important role in the product decision-making process. The research content of usability evaluation mainly focuses on the relationship between the user and the product to measure the use effect of the product and comprehensively analyzes the various decision-making factors that affect the use effect of the product through user questionnaire survey, product use environment simulation, and collection of user behavior data of using products [3, 4]. Usability evaluation research methods mainly include qualitative user observation and quantitative usability test ranking. Such research method focuses more on the realization effect of a single factor of the product function and fails to comprehensively consider the influencing factors of the evaluation, which makes it difficult for the evaluation conclusion to fully and accurately reflect the actual evaluation effect.

As the user-centered product concept has been widely concerned by researchers, the evaluation of product usability emphasizes more on the perspective of nonproduct factors such as user perception and experience and pays attention to the impact of multiple heterogeneous factors on product usability. The advantages of Fuzzy Analytic Hierarchy Process (FAHP) in solving the decision-making problem of multifactor events have begun to be valued by researchers. Fuzzy Analytic Hierarchy Process is an effective multicriteria decision-making method for quantitative analysis of qualitative problems. It expresses people's cognitive strength of things with fuzzy numbers and quantitatively deals with different index factors that affect decision-making goals and solves the problem of usability, solves the problems of many usability index factors and fuzzy users' subjective judgment, and can effectively guide product usability decision-making [5].

*2.2. Microscope Usability Evaluation Research.* With microscope as a basic scientific observation instrument, its usability evaluation has become a hot point in the usability research of scientific observation instruments.

The usability evaluation of the microscope is a complex system, which is affected not only by product factors but also by nonproduct factors and other multiple heterogeneous factors, and its evaluation effect depends on the systematic measurement of different index factors. According to the concept of usability research, the usability evaluation of multiple heterogeneous factor-driven microscopes is to measure the effect of the microscope from the perspective of different perspectives such as user interaction experience and product structure, focusing on operating efficiency, effectiveness, and user satisfaction. The research of the usability evaluation of the microscope is based on the research trend of multiperspective and multidiscipline integration, and the relationship between users and the microscope is discussed based on different application scenarios, to measure its application effect. According to the content of the research and the focus, the usability evaluation of the microscope can be divided into three aspects: ① Focusing on the usability evaluation of man-machine interactive experience between users and microscopes; ② usability testing based on microscope products in specific application environments; ③ measuring the usability of the microscope product structure for specific observation tasks [6–8]. According to different evaluation content, the usability evaluation method of microscope not only involves a subjective questionnaire, but also involves the user physiological data collection and product structure data analysis in the process of microscope use. For example, Loukas et al. used video analysis to analyze the operation actions of surgeons using microscopes to measure the effectiveness of microscope use [9]. Rodrigues et al. used finite element analysis to evaluate the usability of the force state of the microscope structure in a particular observation task [10]. Although there are many dimensions and methods for evaluating the usability of the microscope, there are not enough researches on evaluating the overall application effect of multiple heterogeneous factor-driven microscopes.

Recently, with the application of microscopes constantly expanding, the application field of microscope has been expanded from scientific research observation to teaching; on this basis, the research of the usability of microscope in specific pedagogical tasks has begun to receive the attention of researchers. The research is mainly with the subjective learning experience of students and aims to enhance their interest in learning microscopes by combining the application of emerging technologies with the process of using microscopes in class. For example, Alyssa et al. aimed at different microscope observation tasks, by selecting different types of microscope and teaching aids, thereby improving the subjective satisfaction of students with microscope learning [11]. Wang et al. used intelligent algorithms to create an interesting microscope experience, to improve students' satisfaction with microscope [12].

Overall, the usability evaluation of the microscope focuses not only on the appearance and structure of microscope products, but also on the experience of multiple heterogeneous factors such as the efficiency and subjective satisfaction of the microscope during use, especially the effective application of microscopes in specific pedagogical tasks. However, the research at present still has some limitations: ① Research content: The existing researches of microscope usability evaluation mainly focus on single-dimensional issues such as the product structure of the microscope or subjective satisfaction and seldom measure the overall effect of the microscope from the multidimensional perspective such as product operation efficiency, effectiveness, and user satisfaction, especially in the microscope teaching application scenario; the single evaluation criteria cannot systematically balance various demand elements in the teaching application of multiple heterogeneous factors-driven microscope. ② Research methods: the existing researches on the usability of microscopes mainly use questionnaires and qualitative observation methods to collect students' subjective satisfaction of using the microscope, research on quantitative analysis of the behavioral data of students using microscopes, and the structural features of microscopes, which weakens the accuracy of the evaluation results of microscope and cannot comprehensively guide the design optimization of microscope.

## 3. Materials and Methods

*3.1. Research Methods.* This research is guided by the usability evaluation of microscopes, using Fuzzy Analytic Hierarchy Process combined with microscope user observation and product structure finite element analysis to construct a microscope usability evaluation model to guide microscope usability design and usability evaluation.

*3.1.1. Fuzzy Analytic Hierarchy Process.* This research uses the Fuzzy Analytic Hierarchy Process to analyze the usability evaluation elements of microscopes from the interaction between students and microscope products, analyzes the usability elements of multiple heterogeneous factor-driven microscope around the operational efficiency, effectiveness, and subjective satisfaction of the usability theory, summarizes the usability evaluation indexes, and clarifies the weight of each index, to construct the microscope usability evaluation model and provide guidance for the optimization of microscope usability design.

*3.1.2. User Observation Method.* To extract the usability evaluation elements involving the user experience during the interaction between students and the microscope, the video information of students' use of the microscope process is recorded by User Observation Method, and the behavior information of students using the microscope is captured by Kinovea video analysis software widely used in user observation analysis, thus providing the usability elements of the user experience for the usability evaluation of the microscope.

*3.1.3. Finite Element Analysis.* The usability evaluation elements related to the product structure cannot be directly observed during the interaction between student and microscopes; through product structure finite element analysis, using ANSYS finite element analysis software, the complex microscope model is converted into a limited amount of unit testing of product structure, to provide usability elements such as product structure features for the usability evaluation of the microscope.

*3.1.4. Jack Virtual Simulation Analysis.* Jack software is one of the mature software programs evaluated in the world in terms of simulation and man-machine efficiency. It has a very rich and comprehensive digital human model. By analyzing how the digital human performs tasks, the data conclusions are obtained, the human-machine system is improved, and the product design is optimized, so that the designed microscope can satisfy the user's comfort to the greatest extent, and the human-machine efficacy analysis is more targeted and accurate.

*3.2. Research Framework.* The research framework of microscope usability evaluation based on Fuzzy Analytic Hierarchy Process is shown in Figure 1.

(1) Based on the usability theory, the User Observation Method and Finite Element Analysis Method are used to obtain the usability evaluation elements during the use of microscopes.
(2) The usability evaluation elements of the microscope are analyzed by Fuzzy Analytic Hierarchy Process, defining multiple heterogeneous factor-driven usability evaluation indexes and index weights surrounding the operational efficiency, effectiveness, and user satisfaction, and the usability evaluation model of microscope is constructed, and the usability evaluation of microscope is carried out according to the model.
(3) According to the microscope usability evaluation model and the existing microscope usability evaluation results, the microscope usability design optimization is carried out.
(4) Use Jack simulation software and ANSYS finite element analysis software to carry out simulation tests on the user interaction process and product structure of the microscope optimization scheme, respectively. Combined with the simulation test results, the usability score of the optimized microscope is calculated according to the usability evaluation model, to verify the usability of the microscope optimization scheme.

## 4. Analysis of the Elements of the Microscope Usability Evaluation

*4.1. Microscope Usability Evaluation Element Analysis Based on User Observation.* The analysis of microscope usability

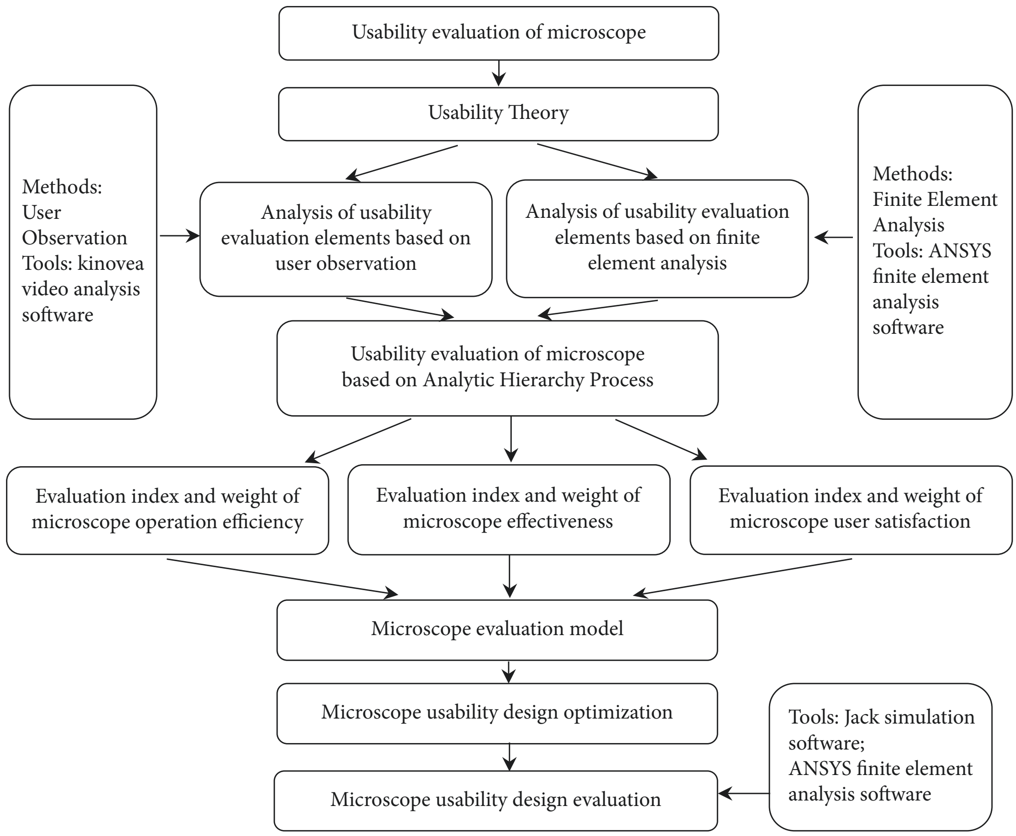



Figure 1: Research framework.

evaluation elements based on user observation revolves focus on the operational efficiency, comfort, and observation effect of the microscope use process. The analysis of microscope usability evaluation elements based on user observation is carried out in three different dimensions: operating efficiency, comfort, and observation effect of the microscope use process. The operation efficiency refers to the change in the operation efficiency of the microscope caused by the environment, such as the intensity of light and whether the desktop is flat; comfort refers to the subjective comfort of the microscope during operation from the user's point of view; the observation effect refers to the influence of the material, structure, and other factors of the microscope itself on the correctness of the observation results. The observation objectives mainly include recording the characteristics of hand operation, neck condition, and observation effects of the students during using the microscope in class.

The subjects of observation were four junior high school students from the same school in Henan Province, China, including two boys and two girls, their physical condition is healthy, their visual acuity levels are consistent, and all are at a good level. The subjects were selected for their level of microscopic performance and their scores were above the pass line in the most recent microscopic performance evaluation. The subjects and their guardians have been informed of the content of the evaluation and have signed an informed consent.

Observation tools include a camera to record the student's operation, a triangular stand to secure the camera, a tape measure for measuring the standard distance in the calibration video, a microscope (Ministry of Education, designated model: XSP02), a microscope observation sample (tomato flesh sample), and black circular tracking label that captures the movements of the student's hand.

The observation process consists of three stages: ① The camera was set up 2 meters on the side of the object before observation, at a height of 1.5 meters, and a tracking label was set at the wrist, ears, shoulders, and hips of the observer. ② A video camera was used to record the students using the same microscope to observe the tomato sample. ③ After observation, the professional teacher was asked to rate the observation effect of the student's tomato flesh sample. The observation process is shown in Figure 2.

Analyze the observation data. To obtain the usage status of different operation links of the microscope, the microscope operation video was imported into Kinovea software, and the video was divided into 4 segments according to the operation content: adjusting condensers, placing samples, focusing and observation, and putting away the microscope. Focusing on the operating efficiency, comfort, and observation effect of microscopes, the following three statistics were made on the microscope usage data in different video clips.

Figure 2: User observation.

Table 1: Students' hand movement data for different operations.

| Operation process | Hand motion time (s) | Hand motion distance (mm) | Average speed of hand motion (mm/s) |
|---|---|---|---|
| Adjusting condensers | 33.00 | 1359.00 | 41.18 |
| Placing samples | 19.00 | 1907.00 | 100.37 |
| Focusing and observation | 61.00 | 1341.00 | 21.98 |
| Putting away the microscope | 14.00 | 5701.00 | 407.21 |

(1) Aiming at the operational efficiency of each link of microscope, a representative object of observation was selected as the analysis sample, and Kinovea software was used to track the motion distance, motion time, and average speed of the hand in four different links of operation, and a table was drawn, as shown in Table 1. The overall operation efficiency of the microscope is not high, in each operation link, the condenser adjusting and focus observation takes a long time, and the hand movement speed is also the slowest, respectively, 41.18 mm/s and 21.98 mm/s. Combined with the video content, it is found that students need to adjust the condensers for a long time to find the best light source due to the influence of ambient light, and the operating efficiency is lower. In the process of focusing operation, students should adjust the focusing knob with different precision repeatedly, which results in high error rate and low efficiency.

(2) Focusing on the comfort of using the microscope, we use the tracking tag to obtain the changes in the neck angle of the observed object during the microscope operation, and the relationship between students' neck angle deviation and time during the use of the microscope was drawn, as shown in Figure 3. In the whole process of using the microscope, the students' necks were bent at a large angle for a long time. During the sample placement, the neck angle deviation was large, with the maximum angle exceeding 85°. In the process of focusing and observation, the neck length of the students was bent over 60° for a long time, and students have a poor experience of using microscopes.

(3) To compare the effect of different operating links on the observation effect of the microscope, the observation scores of 4 students were ranked according to the clarity of the microscope observation results, and the time spent by students with different observational scores in each operation link was shown in Figure 4. Generally, the operational efficiency of students with good performance is relatively high. Among them, the students with poor performance spent much more time in focusing and observation than those with good performance. It can be seen that the focusing operation during the use of the microscope is difficult for students to grasp, and the increase in the difficulty of operation affects the observation effect of the microscope.

The above observation and analysis of the use of microscopes are combined to extract the elements of microscope usability that affects the user interaction experience: ① The main influencing elements to the operation efficiency of microscope are the condenser adjusting and focusing operation, and the corresponding product function layout affects the hand operation rate. ② A greater impact on the comfort of using a microscope is the placement of samples and the focus observation process, which involves microscope components that are not flexible enough to fit the student's neck posture and affect the student's operating experience. ③ In terms of the observation effect, the complexity of the functional structure of the microscope increases the difficulty for students to operate the microscope; in particular the more complex focusing structure affects the observation effect of the microscope.

*4.2. Microscope Usability Evaluation Element Analysis Based on Finite Element Analysis.* Reasonable product structure of microscope affects the usability of the microscope to some extent; in particular the ability of resisting fracture and deformation of each part of microscope is the basis of its effective use. ANSYS finite element analysis software can test the rationality of the product structure of the microscope by simplifying the complex microscope structure and analyzing the stress and strain data of the components of the microscope in a particular use. The analysis process is as follows:

(1) Constructing the finite element model of microscope:

Firstly, the three-dimensional model of the microscope equipment (XPS02) is established by using the 3D model, and secondly, the process of condenser adjustment, focus, and observation, which are most clearly affected by external forces, is selected, and the

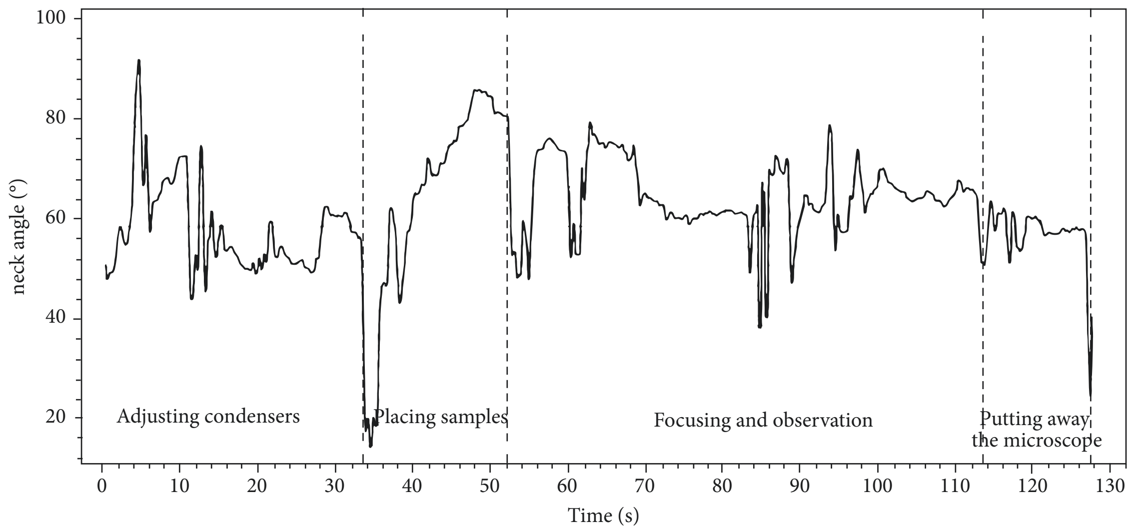



FIGURE 3: The students' neck angle changes in different operation links.

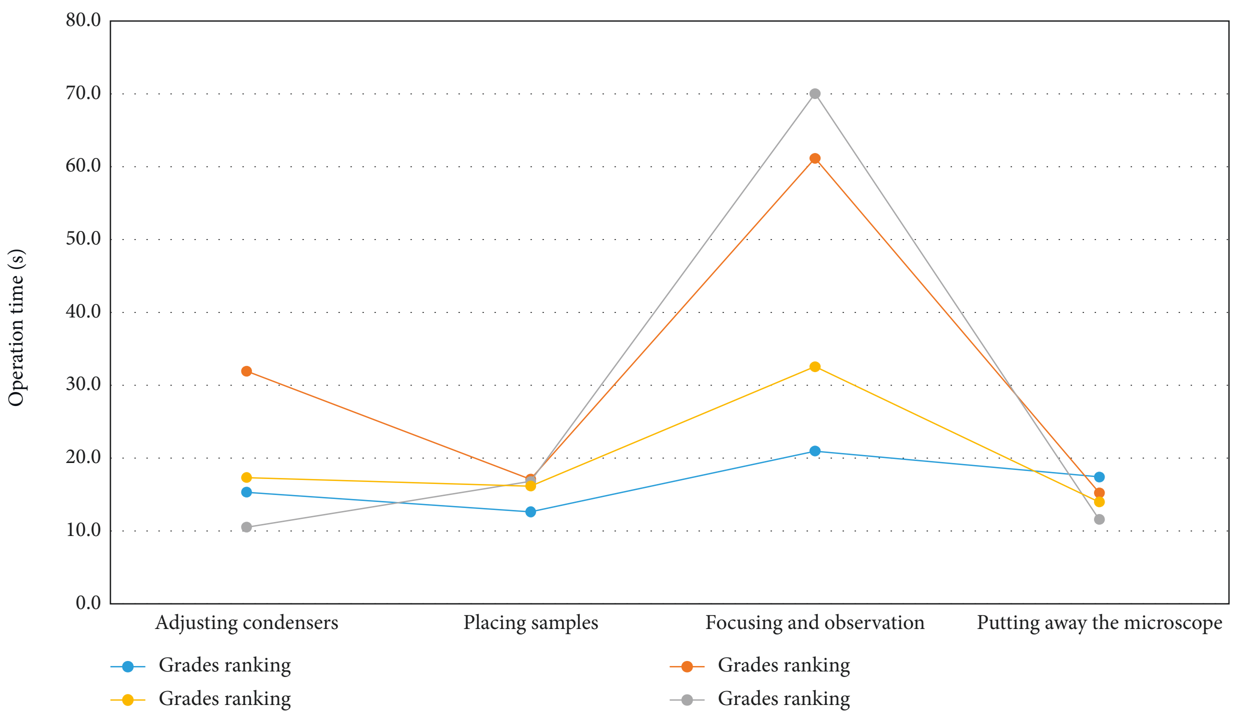



FIGURE 4: The operating time of students with different grades was observed.

model is adjusted according to the corresponding state of use. Finally, the models in different states were imported into ANSYS finite element analysis software, respectively. According to the material properties of the main structure of microscope, the model materials were defined as cast iron and aluminum alloy, and the material properties were shown in Table 2.

(2) Define constraints and loads:

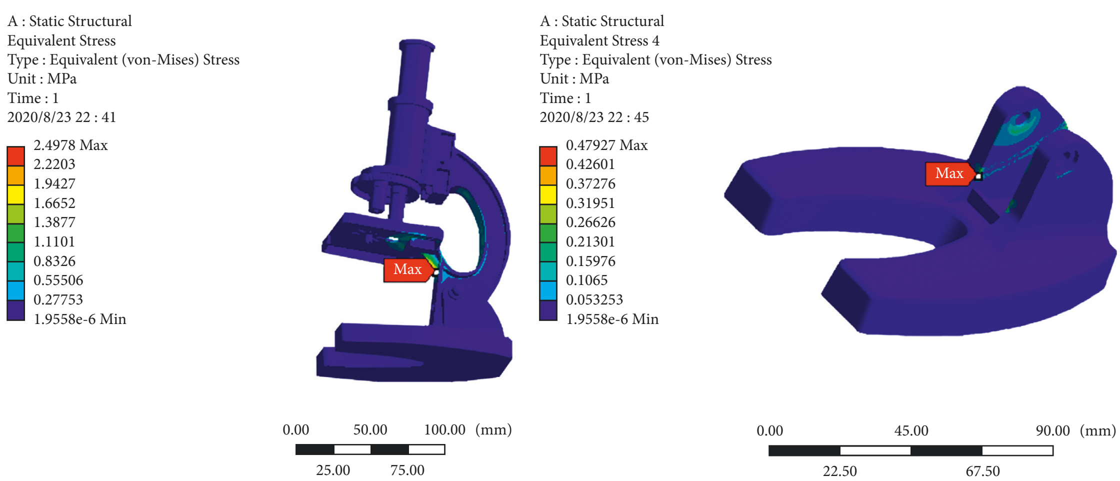
The three-dimensional model of the microscope was imported into the Workbench module of ANSYS software, and the connection and force relationship among various parts were determined according to the three statuses of microscopes, so as to apply the corresponding boundary conditions and loads.

(3) Analyze the results:

Carry out the static analysis of each component of the microscope in different working states, select the working state with the greatest force on each component to calculate the stress and strain of them, and the stress and strain nephograms of the microscope arm and base are obtained, as shown in Figures 5 and 6. From the overall stress of the components, the maximum stress and strain of each

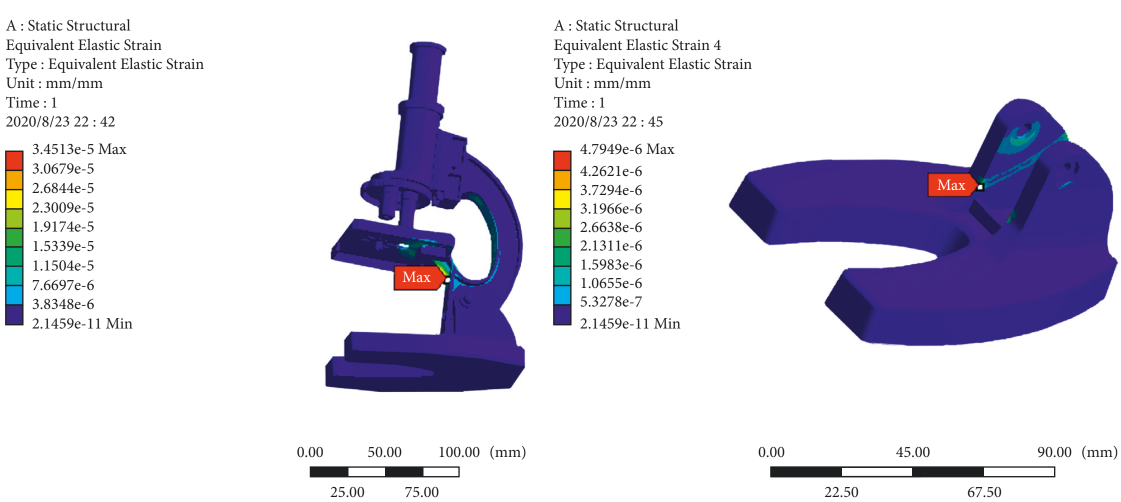
Table 2: Material properties of the main structure of microscope.

| Material | Density (p)/kg $m^{-3}$ | Elastic modulus ($E$)/Gpa | Yield strength (Rp0.2)/Mpa | Poisson's ratio ($\sigma$) |
|---|---|---|---|---|
| Cast iron | 7350 | 115 | 165 | 0.27 |
| Aluminum alloy | 2750 | 72.6 | 276 | 0.33 |




(a) (b)

Figure 5: Microscope stress nephogram. (a) Microscope arm stress nephogram. (b) Base stress nephogram.




(a) (b)

Figure 6: Microscope strain nephogram. (a) Microscope arm strain nephogram. (b) Base strain nephogram.

component are far less than the affordability standard of microscope materials; microscope product structure has the condition of material overuse; although the use of cast iron microscope safety load standard is high, the appearance is relatively heavy, costly, and easy to corrode. For the force situation of the microscope arm, the maximum stress and strain occur at the junction with the stage, which are 2.498 MPa and 0.0345 mm, respectively, although within the structural tolerance range, the stability of the product component connection and the compactness of the appearance structure which is exposed by the stress and strain distribution is the factor affecting the effective use of the microscope. In terms of the stress of the base, the maximum stress and strain occur in the protrusions of the base, which are 0.479 MPa and 0.0047 mm, respectively. Although far below the safety standard, the stress concentration risk of such protrusions should be reduced by optimizing the appearance and structure of the components. The structural analysis of different levels of the above microscope shows that the suitable material selection of the microscope, the stability of the component connection, the integrity, and compactness of the appearance structure are

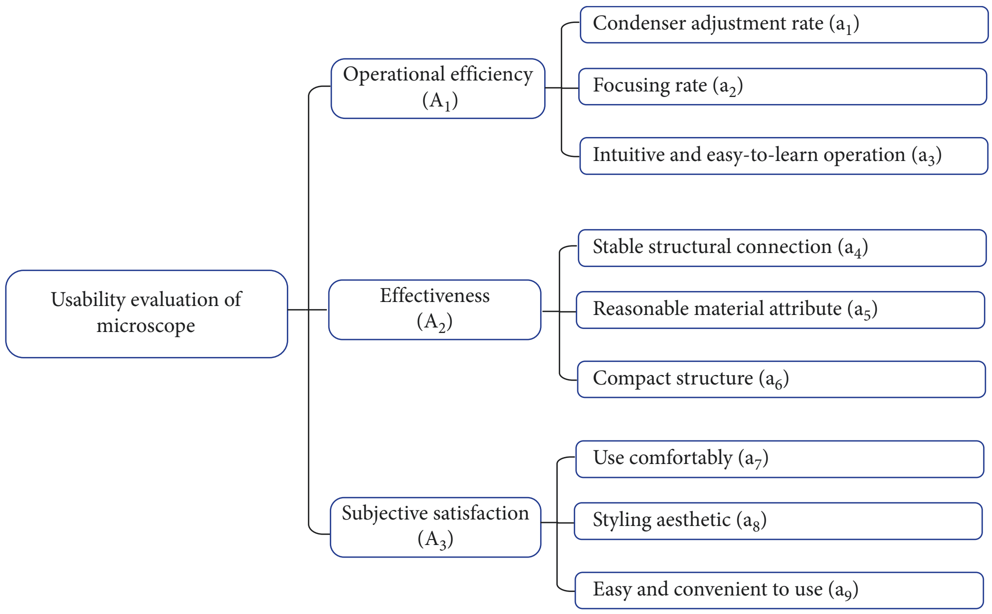



Figure 7: Microscope usability evaluation index system.

the elements that need to be considered for its effective application.

## 5. The Usability Evaluation Model of Microscope Based on Analytic Hierarchy Process

From the above analysis of microscope usability elements based on user observation and product structure finite element analysis, the Analytic Hierarchy Process is used to quantitatively analyze multiple heterogeneous factors, and the evaluation index and their weights are clarified, to construct a microscope usability evaluation model. The steps of evaluating the usability of microscopes by using Analytic Hierarchy Process are as follows.

*5.1. Constructing Usability Evaluation Index System.* To analyze the hierarchical relationship between usability elements, the usability of microscope is decomposed hierarchically, and the usability evaluation index system is established. Invite 5 microscope designers, 2 microscope professional teachers, and 2 students to form a focus group to discuss the usability evaluation of the microscope. With microscope in the early stage of the class based on the analysis of usability, the focus group combined with the literature data and expert advice, according to the connotation of the product usability from the three layers of operational efficiency ($A_1$), effectiveness ($A_2$), and subjective satisfaction ($A_3$), build 9 usability indexes of microscope usability evaluation index system, as shown in Figure 7. Among them, the operational efficiency layer includes the condenser adjustment rate ($a_1$), focusing rate ($a_2$), and intuitive and easy-to-learn operation ($a_3$), the effectiveness level can be decomposed into stable structural connection ($a_4$), reasonable material attribute ($a_5$), and compact structure ($a_6$), and subjective satisfaction involves the three aspects of use comfortably ($a_7$), styling aesthetic ($a_8$), and being easy and convenient to use ($a_9$).

*5.2. Construct a Judgment Matrix for Evaluation Index.* To calculate the weight value of the index at all levels, the pairwise comparison is used to construct the evaluation index judgment matrix to calculate the weight value of indices. The 1–9 scale method is used to compare and assign the properties of each index and constructs the index judgment matrix: $E = \{ a_{ij}, i = 1,2, \ldots, m; j = 1,2, \ldots, n \}$; among them, $a_{ij}$ represents the contribution of element $a_i$ and element $a_j$ to the superior index.

*5.3. The Calculation of Evaluation Index Weight.* Since the relative weight of the index is relative to the index at the previous level, the relative weight of each index must be normalized by judging the characteristic vector of the matrix. The calculation process includes the following:

(i) Calculate the product $m_i$ for each row of the judgment matrix:

$$M_i = \prod_{j=1}^{n} a_{ij}. \quad (1)$$

(ii) Judge the components of the eigenvector of the matrix, that is, the N th square root of the product of each row:

$$\overline{W_i} = \sqrt[n]{M_i}. \quad (2)$$

(iii) The feature vector is normalized to determine the relative weight $W_i$ of this layer index to the upper level index:

Table 3: Average random consistency index.

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

$$W_i = \frac{\overline{W_i}}{\sum_{i=0}^{n} \overline{W_i}}. \tag{3}$$

Calculate the weight vector of each index in the index layer: $W$=(0.15, 0.09, 0.04, 0.14, 0.13, 0.16, 0.22, 0.04, 0.04)T°

*5.4. The Consistency Test of the Evaluation.* To ensure the consistency of the evaluation process of the usability index weight of microscope, after the weight value of the index is obtained, it is calculated according to formulas (3)–(5) for the consistency test:

$$\begin{aligned} CR &= \frac{CI}{RI}, \\ CI &= \frac{\lambda_{\max} - n}{n - 1}, \\ \lambda_{\max} &= \frac{1}{n} \sum_{i=1}^{n} \frac{(AW)_i}{W_i}. \end{aligned} \tag{4}$$

Among them, CR is the random consistency ratio, and $\lambda_{\max}$ is the maximum characteristic value of the judgment matrix. Maximum eigenvalue $\lambda_{\max} = 1/n \sum_{i=1}^{n} (AW)_i/W_i = 1/9\,(88.20) = 9.80$; consistency index $CI = \lambda_{\max} - n/n - 1 = 9.80 - 9/8 = 0.1$. According to Table 3, the random consistency coefficient RI = 1.45 when the matrix order is 9, so $CR = CI/RI = 0.1/1.45 = 0.068 \ < 0.1$, which satisfies the consistency condition. Therefore, the weight of the microscope usability evaluation index is reasonable.

*5.5. Construct the Usability Evaluation Model of Microscope.* According to the above usability indexes and weights of microscope operational efficiency, effectiveness, and subjective satisfaction, a microscope usability evaluation model is constructed, including the target layer, criterion layer, index layer, and corresponding index weights, as shown in Table 4. In terms of the weight of the criterion level, the weight of microscope operational efficiency is 43.0%, and the weights of effectiveness and subjective satisfaction are 28.0% and 30.0%, respectively. The weight of microscope operation efficiency is more important than the other two usability criteria, which indicates that the usability of microscopes should be based on its basic functions and attach importance to the operation experience of the microscope; in terms of the weight of the index layer, the use comfort of the microscope and intuitive and easy-to-learn operation account for a larger weight, accounting for 22.0% and 16.0%, respectively, indicating that the design of the usability of the microscope in the teaching situation should pay more attention to the human-machine relationship between students and the microscope and the ease of operation.

Table 4: Microscope usability evaluation model.

| Target layer | Criterion layer | Index layer | Weight (%) |
|---|---|---|---|
| Usability evaluation of teaching microscope | A1: Operational efficiency | a1: Condenser adjustment rate | 14.0 |
| | | a2: Focusing rate | 13.0 |
| | | a3: Intuitive operation and easy to learn | 16.0 |
| | A2: Effectiveness | a4: Stable structural connection | 15.0 |
| | | a5: Reasonable materials attribute | 9.0 |
| | | a6: Compact structure | 4.0 |
| | A3: Subjective satisfaction | a7: Use comfortably | 22.0 |
| | | a8: Styling aesthetic | 4.0 |
| | | a9: Easy and convenient to use | 4.0 |

*5.6. Existing Microscope Usability Evaluation.* According to the usability evaluation model of microscopes, the usability of microscopes was evaluated, and the evaluation scores were standardized by Likert's 7-level evaluation method, to obtain the usability evaluation of microscopes, as shown in Table 5. According to the weight of the evaluation index, using formula (5) to calculate the usability test score of the existing microscope, $X = 3.53$.

$$\begin{aligned} X = {} & 0.15a_1 + 0.09a_2 + 0.04a_{13} + 0.14a_4 + 0.13a_5 \\ & + 0.16a_6 + 0.22a_7 + 0.04a_8 + 0.04a_9. \end{aligned} \tag{5}$$

From the evaluation results: ① From the criteria layer, the effectiveness and user satisfaction of the existing microscopes still need to be improved. ② From the specific evaluation index, the existing microscopes have inadequate consideration in terms of material properties and structural integrity, resulting in the excessive materials and dimensions of the microscope components; the general performance in terms of comfort in use and the simplicity and beauty of the shape cannot give students a comfortable physical and visual experience. Therefore, the design and optimization of microscope should focus on the usability evaluation model from the aspects of functional structure, product materials, and appearance modeling, to bring better learning experience to students.

## 6. Microscope Usability Design Optimization and Fuzzy Comprehensive Evaluation

*6.1. Optimization of Microscope Usability Design.* According to the results of the microscope evaluation, and around the three aspects of efficiency, effectiveness, and subjective satisfaction, the microscope is designed and optimized, and an optimization scheme is output by Proe parametric modeling software, as shown in Figure 8.

Table 5: Microscope usability score.

| Condenser adjustment rate | Focusing rate | Intuitive and easy-to-learn operation | Stable structural connection | Reasonable material attribute | Compact structure | Use comfortably | Styling aesthetic | Easy and convenient to use |
|---|---|---|---|---|---|---|---|---|
| 4 | 4 | 3 | 6 | 3 | 3 | 2 | 3 | 3 |

Figure 8: Microscope design optimization.

In terms of the operational efficiency of microscope, the efficiency of adjusting condensers is improved by changing the illumination mode of the microscope from reflector type to the electron fluorescence type, and the button operation is used to replace the complex reflector angle adjustment. To improve the efficiency of focusing operation, the focusing knob is moved down, so that the user can operate the knob with a more natural arm angle, thus improving the convenience of operation.

In terms of the effectiveness of the use of microscopes, the effective teaching application of the microscope is ensured. The structural integrity of the microscope can be improved by reducing the structural connection of the microscope, to improve the stability of the product structure. In terms of material appearance, the use of non-load-bearing microscope components is reduced by changing non-load-bearing microscope components to ABS materials; ABS materials have excellent comprehensive performance with low density, high elasticity and toughness, strong impact resistance, chemical corrosion resistance, and certain surface hardness, and the microscope arm design is designed in a hollow form to reduce the use of nonessential materials, ensuring the stability of microscopes while reducing material consumption.

To improve the subjective satisfaction of using the microscope, the design optimization is mainly carried out from the aspects of improving the user's operating comfort and sensory experience. For improving user comfort, the front and rear angle adjustment of the microscope arm is mainly used to reduce the large angle bending of the user's neck and other joints, thus avoiding the user's physical discomfort. For the enhancement of the sensory experience of the microscope, it is mainly from the aspects of reducing the exposed mechanical structure and improving the appearance smoothness to make the microscope more in line with the aesthetic taste of students.

*6.2. Evaluation of the Usability Design of Microscopes.* To verify the effect of microscope usability design optimization, Jack simulation software and ANSYS finite element analysis software are used to simulate the user interaction and product structure of microscope after design optimization, to evaluate the operational efficiency, effectiveness, and subjective satisfaction of microscope.

Jack simulation software can quickly and accurately simulate the user's posture and stress state during the use of the product and quantitatively evaluate the usability of the product in the process, and thus it is widely used in product usability testing. By importing the microscope model into Jack simulation software, simulating the process of students using microscope in teaching scene, the operational efficiency and user comfort of microscope optimization schemes are quantitatively evaluated, as shown in Figure 9.

In the evaluation of product operating efficiency, the operational efficiency of the microscope is evaluated by simulating the time used by microscopes in different operations. MTM Time Evaluation module in Jack simulation software will be used to subdivide the actions and define unit time for adjusting condensers, placing samples, focusing observation, and other processes, to obtain the optimized operating time of the microscope, as shown in Table 6. The overall operating time of the optimized microscope is 63s, which is improved comparing to the microscope before optimization, especially in adjusting condensers and focusing observation.

In terms of the evaluation of comfort, the physical comfort of the students during the user process is calculated by simulating the posture of the student operating the microscope, using the Comfort Evaluation module in Jack simulation software to define the angle of the user's neck, wrist, and other joints prone to fatigue problems, as shown in Figure 10. The green data in the comfort score indicates that the corresponding joint bending degree is within a reasonable range, and the value closer to 0 represents the better comfort. Judging from the comfort score of each joint, the comfort of each joint is better during operation, and the bending degrees of the neck and hands are in a reasonable range of man-machine operation.

The optimized microscope model is imported into ANSYS finite element analysis software for product structure simulation testing. By calculating the force state of the microscope in each operation, define the load of each component of the microscope, then select the microscope arm and base with the greatest force for static analysis, and obtain the stress and strain nephogram of the microscope arm and base, as shown in Figure 11 and 12. The maximum stress and strain of the microscope arm were 9.335 MPa and 0.0265 mm, respectively, which were within the standard range of aluminum alloy; the maximum stress and strain of the microscope base are 0.285 MPa and 0.0016 mm, respectively, and did not exceed the ABS maximum tolerance

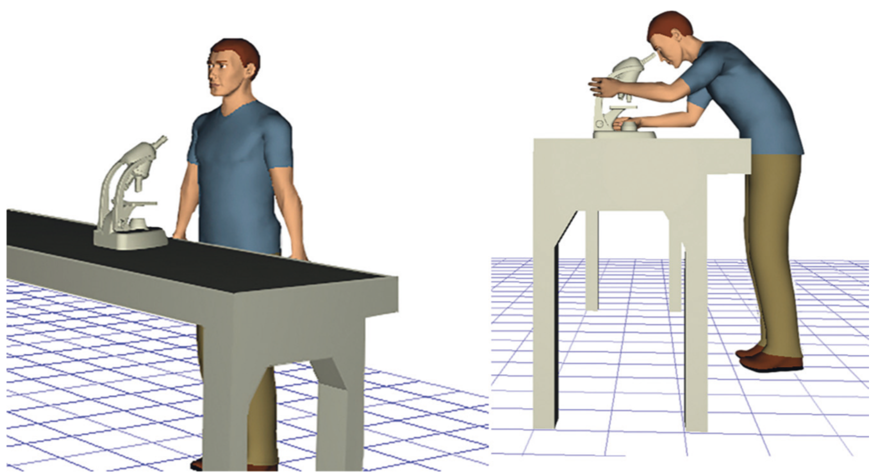


Figure 9: The use process simulation of microscope based on Jack software.

Table 6: Microscope operation time.

| Operation number | Operation process | Task description | Task time (s) |
|---|---|---|---|
| 1 | Adjusting condensers | Adjusting focus knob | 2 |
| 2 | | Adjust objective | 2 |
| 3 | | Turn on the illuminator | 1 |
| 4 | Placing samples | Adjust the focus knob; place the samples | 15 |
| 5 | | Place the samples | 15 |
| 6 | Focusing and observation | Adjust the focus knob | 26 |
| 7 | Putting away the microscope | Adjust the focus knob | 6 |
| 8 | | Pick up the sample | 1 |
| 9 | | Adjust objective | 8 |
| 10 | | Turn off the illuminator | 1 |
| Total time | | | 63 |

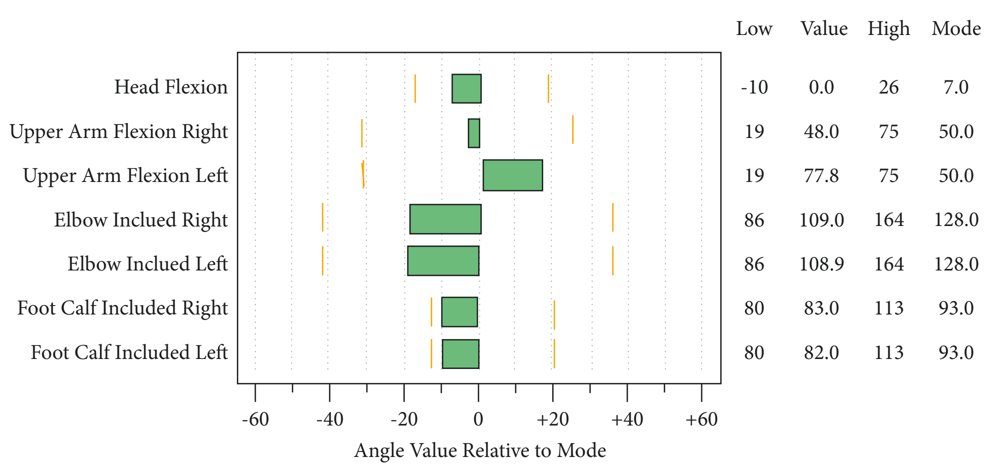


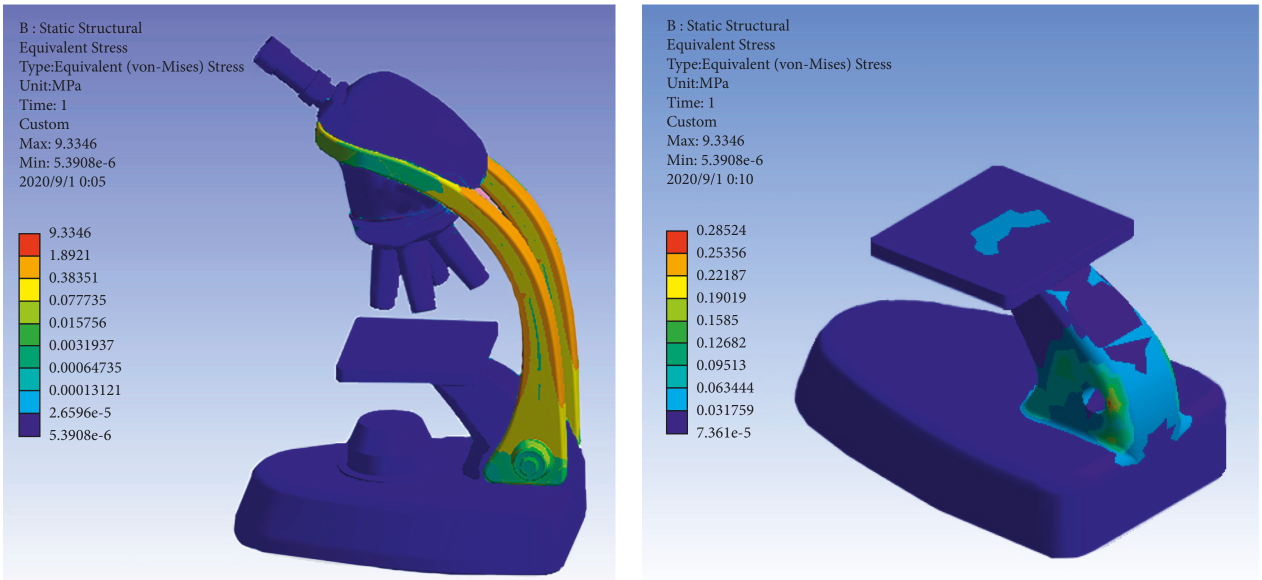

Figure 10: The body comfort test during the use of microscope.

standard. Therefore, the use of lower dense materials can reduce the weight of the microscope while the stability of the product structure is still good.

Based on the above, Jack simulation software and ANSYS software are used to test the usability of the microscope. According to the microscope usability evaluation model, the fuzzy comprehensive evaluation of the microscope design optimization scheme mainly involves the following steps.

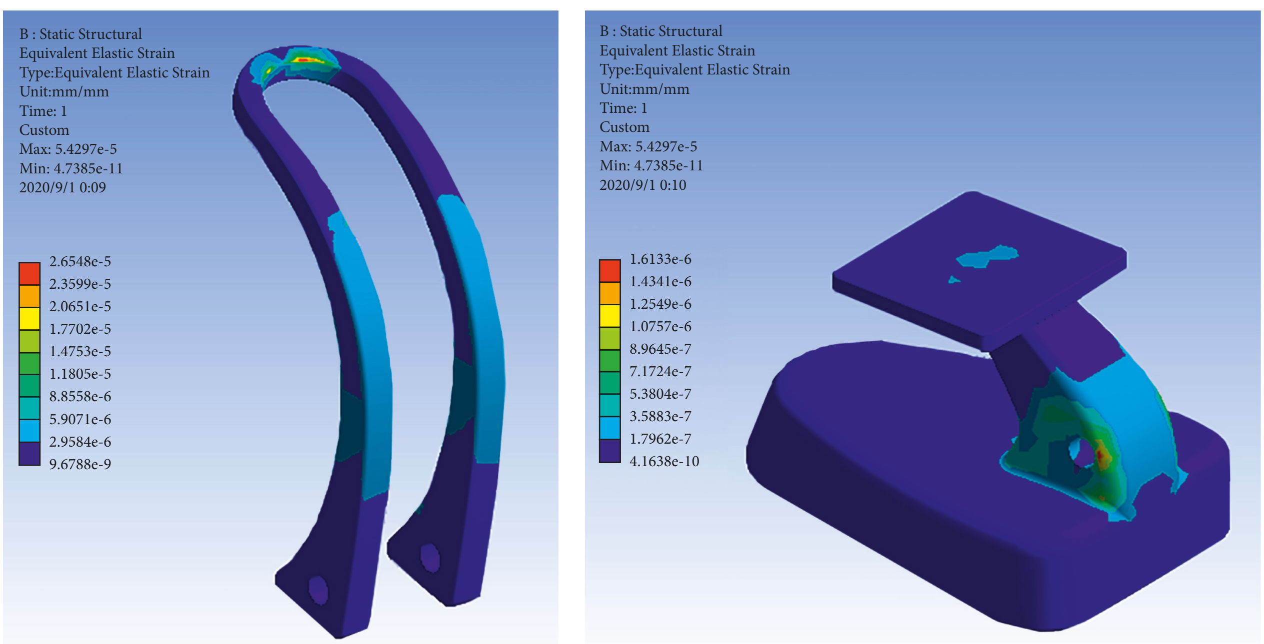
(1) Determine the fuzzy evaluation index set and evaluation grade, set the index set as $a = \{b_1\ b_2\ b_3\}$, divide the evaluation results into grades, and record them as $V = \{V1,\ V2,\ V3,\ V4\}$, where the excellent score is $> 90$; good 80–90; qualified 60–80; unqualified $<60$.

(2) Determine the evaluation weight. According to the index weight of Analytic Hierarchy Process, the




(a) (b)

Figure 11: Optimized microscope stress nephogram. (a) Microscope arm stress nephogram. (b) Base stress nephogram.




(a) (b)

Figure 12: Optimized microscope strain nephogram. (a) Microscope arm strain nephogram. (b) Base strain nephogram.

operation efficiency weight $W1$ = (0.15, 0.09, 0.04), the effectiveness weight $W2$ = (0.14, 0.13, 0.16), and the subjective satisfaction weight $W3$ = (0.22, 0.04, 0.04).

(3) Carry out a fuzzy comprehensive evaluation, organize a focus group composed of designers, microscope teachers, and students, evaluate the microscope in terms of operation efficiency, usability, and user subjective satisfaction according to the above test results, count the scores in the form of Likert 7 scale, and present the evaluation results, as shown in Table 7.

Combined with the evaluation results, the score of the microscope on each index is weighted according to the microscope usability evaluation model. Finally, the usability score $x = 5.31$, which is greater than the usability score of 3.53 before improvement. The evaluation results are normalized and the weight of usability index is weighted and

Table 7: Usability score of microscope optimization design scheme.

| Target layer | Criterion layer | Index layer | Weight (%) | Score |
|---|---|---|---|---|
| Usability evaluation of teaching microscope | A1: Operational efficiency | a1: Condenser adjustment rate | 14.0 | 6 |
| | | a2: Focusing rate | 13.0 | 5 |
| | | a3: Intuitive and easy-to-learn operation | 16.0 | 4 |
| | A2: Effectiveness | a4: Stable structural connection | 15.0 | 6 |
| | | a5: Reasonable materials attribute | 9.0 | 4 |
| | | a6: Compact structure | 4.0 | 5 |
| | A3: Subjective satisfaction | a7: Use comfortably | 22.0 | 6 |
| | | a8: Styling aesthetic | 4.0 | 4 |
| | | a9: Easy and convenient to use | 4.0 | 4 |

calculated. After normalization, the evaluation grade of usability target V can be obtained. The score shows that the usability grade is excellent. The usability of the improved microscope is better than that of the unmodified microscope as a whole. In particular, the usability of microscope structure, connection, comfort, optical operation efficiency, and focusing operation efficiency are greatly improved. Therefore, the optimized microscope has good usability and meets the needs of microscope teaching and application.

## 7. Result

To promote the effective application of microscope in the complex teaching scenes, this research proposed a usability evaluation of the multiple heterogeneous driven factors microscope. Based on the theory of usability design, we construct a usability evaluation model with Fuzzy Analytic Hierarchy Process (FAHP). The usability evaluation of microscopes is conducted from three different aspects of operating efficiency, effectiveness, and user satisfaction, to guide the optimization of microscope usability design. The results show the following: ① In terms of the operating efficiency of the microscope affected by the environment, Intuitive and easy-to-learn operation and condenser adjustment rate account for the largest weight among all indexes, which are 16% and 14%, respectively. For the microscope itself, the operating efficiency can be improved by using an electric illumination source and adjusting the position of the focusing knob. ② In terms of effectiveness, the two usability indexes of stable structure connection and reasonable material attribute account for the largest weight, which are 15.0% and 9.0%, respectively, the stable structural connection can be improved under permissible stress by enhancing the structural compactness of the microscope and using materials with lower density. ③ In terms of subjective satisfaction of users, users have the highest usability rating for the comfort index of the microscope. The appearance and functional layout of the microscope can be adjusted to improve the comfort of the users' neck and other limbs. The results proved that the usability evaluation model of multiple heterogeneous driven factors microscopes can comprehensively evaluate the application of microscopes in complex teaching scenarios and also can effectively guide the design optimization of the microscope. It should be pointed out that the usability evaluation model of microscope constructed in this research has not been tested and calibrated by a large number of microscope samples, and the accuracy of its index and weights needs to be further improved.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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