Evaluation of Work Posture When Assembling a Study Chair in Industrial Engineering Design Practicum 2

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Abstract. In a study chair assembly workstation facility at Industrial Engineering Design Practicum 2 (IEDP2), practicum students experienced difficulties, including rotating fixtures, separating bolt and nut components, and changing assembly positions. Kinetics analysis through evaluation of work postures is needed to redesign assembly stations. This paper compares the before and after redesigning of a study chair assembly workstation in IEDP2 based on work posture with kinetic analysis through 3D motion with Kinect and LightBuzz Vitruvius sensors. As many as 20 students were involved, including practicum assistant students and practicum students at the Laboratory of Product Planning and Design (LPPD). Comparison of assembly workstation redesigns was measured using fair and maximum moments, testing through paired t-tests. The significant differences between before and after redesigning a study chair assembly at workstation facilities were statistical ($p < 0.001$). Kinetic analysis showed an increase in improving students' working posture by redesigning workstation facilities, showing a different workload on the upper limbs when assembling.

1 Introduction

Undergraduate Program in Industrial Engineering Universitas Sebelas Maret, Surakarta (IE-UNS) has the vision of becoming a leading industrial engineering higher education provider with an international reputation to support the increasing competitiveness of the national industry. In 2015, the IE-UNS curriculum implemented a complex engineering system [1] through an integrated practicum learning process called the Industrial Engineering Design Practicum (IEDP). Learning in the IEDP is an adaptation to the learning factory (LF) concept by taking the case of the furniture industry in making a study chair. The LF concept seeks a learning atmosphere like in a real manufacturing industry, introducing students to understanding the production floor and developing students' potential [2]. Part of a series of activities, the Industrial Engineering Design (IED) Practicum discusses LF in Industrial Engineering Design Practicum 2 (IEDP2) [3], where materials are designed for students to be able to solve complex engineering problems on integrated systems, including people, materials, equipment, energy, information, and cost [4]. Support for facilities and equipment in IEDP2 is needed, especially to encourage improvement in manufacturing processes, which is one of the most effective ways to improve quality, operational efficiency, and profits. Challenges in the furniture industry include reducing defects, reducing production time, improving working comfort, and increasing client satisfaction [5].

Implementing IEDP2 according to provisions of Permenristekdikti number 44 of 2015 article 17, paragraph 4 states that the load of one practicum credit is 170 minutes/week/semester [6]. IEDP2 weighs two credits with 16 meetings/semester requiring 5440 minutes [1]. Silaen [7] explains that the implementation of IEDP2 activities for each module consists of 10 activity modules, including debriefing activities, composite making, preliminary exams, workshops, report processing, and responses take as much as 6640 minutes, when compared to the regulations there is an excess of 1200 minutes or 18 percent. The time required for the manufacturing process is from six out of ten modules consisting of bench workstations, turning, milling, welding, woodworking, and upholstery, and the finishing process takes 2550 minutes. Assembling a study chair at the finishing workstation takes 360 minutes or 14 percent. Therefore, redesigning assembly workstation facilities is necessary for students to understand production management, even though choosing the right solution can be difficult.

Two students worked on the IEDP2 modules regarding finishing activities of assembling a study chair. In the finishing process, workstation facilities are supported by fixtures to facilitate the student in assembling by turning the fixture base 180° [2]. The rotation movement for assembling utilizes the effect of the friction of the material surface between the anvil as the fixture is made of metal, and the placon roller is made of ABS plastic. Placon roller components in the assembly workstation require the student to adjust the

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movements when assembling part of a study chair. Students on the adjustment movement during the assembly of a study chair appeared to have difficulties, especially when the rotation of the fixture was not smooth, there was no part of the separate place for the bolt and nut components, and repeated relocations of a study chair components because it cannot accommodate all the members of a study chair. This condition allows the student's body position to cause a poor posture when assembling. The causes of awkward posture when assembling a study chair consist of a bent posture when reaching components, a turn posture when assembling and moving components, and when looking for bolt and nut components. This movement is repeated in the one-time assembly process. If students are required to achieve the target completion time, it evokes musculoskeletal disorders (MSDs) [8],[9]. This means that in the initial conditions for the workstation, the study chair assembly did not properly consider the accessibility of students' hands [10],[11]. The application of kinetics to improve the design of a study chair assembly workstation must be made by considering the student's work posture.

The proposed improvement in redesigning the assembly workstation facility will offer benefits, especially practicum comfort for students, through improved work postures. It will have the impact of increasing the flexibility of the assembly process. Comfort practicum is the level of well-being an assembly student feels when interacting with work facilities [12]. Redesign assembly workstation facilities to prevent repetitive work postures that cause MSDs complaints often experienced by students, especially in muscle strength when doing the assembly. The assessment of muscle strength is an essential element of evaluating the student's working posture, which shows a reduction in MSDs [13],[14]. This is indispensable in kinetics according to the functional abilities of the student's body [15]; accuracy and reliability are needed when conducting such an evaluation [16]. The interrelationship between muscle strength (moment fair and moment maximum) through a ROM in the upper limb joints and reduction in the joint moment during functional activity has not been evaluated in students [17]. The muscles tested include the shoulder joint and the elbow joint before and after a redesign of assembly workstation facilities in IEDP2.

The muscle test is designed using the value of the theoretical Grade 4 shoulder flexion muscle strength (holds test position against strong to moderate resistance) based on the manual muscle test (MMT) position from Daniels and Worthingham's Muscle Testing [18],[19]. Predicts maximum muscle strength values and explains the relationship between maximum muscle strength values and theoretical Grade 4. Four types of upper limb movement analysis consisted of moment fair on the shoulder joint, moment fair on the elbow joint, moment maximum in the shoulder joint, and moment maximum in the elbow joint [20]. After calculating the theoretical Grade 4 muscle strength value suitable with body weight and upper limb segment length for each assembling treatment, the isometric maximum muscle strength was measured using a hand-held dynamometer (HHD) [21]. It used a paired t-test (Paired Samples t-Test) with significance at $p < 0.05$ comparative analysis before and after redesigning assembly workstation facilities. This test also found a linear relationship between maximum and theoretical Grade 4 muscle strength scores for the eight experimental tasks involving 20 students. During the experiment, each student assembled a study chair at both workstations with an electric screwdriver powered by a pistol grip.

The paper aims to evaluate student work postures using the kinetics analysis through Kinect sensor SDK and LightBuzz Vitruvius software toward a study chair assembly facility workstation by comparing the results of improving the redesign before and after to determine an acceptable workload for the student population. The proper design of assembly workstation facilities for a population is chosen, and jobs are designed to accommodate most of that student population.

2 Method

2.1 Methods

Suitable with the Declaration of Helsinki, approval was requested and obtained from the Faculty of Medicine ethics committee, Sebelas Maret University, Surakarta. All students gave written consent before participating in this activity.

2.2 Subjects

Twenty students were taken from male assistants of students of the LPPD participating in the activity with health conditions. Neither subject had experience using an electric screwdriver powered by a pistol grip. Their median age was 21 years (range 20-22 years), average hand length was 18.2 cm (range 16.8-20.5 cm), and mean height was 168.5 cm (range 160-175 cm). None of the participants had a history of musculoskeletal injury in the hand.

2.3 Apparatus

Assembly workstation facilities in IEDP 2 to create an efficient space where students can efficiently utilize, access, and organize all tools and equipment needed to complete assembly tasks. This facility is designed as a workstation table for a student assembling a study chair. It has a fixture to unite various parts using nuts and bolts to make complete furniture, as shown in Figure 1. When assembling a study chair using a cordless screwdriver, participants stand in front of an assembly workstation table with active upper limbs. The student's body size adjusts the height of the workstation table with the hands forward.

(a) (b)

Fig. 1. (a) Workstation assembly facilities in IEDP 2 before redesign, (b) Workstation assembly facilities in IEDP 2 after redesign

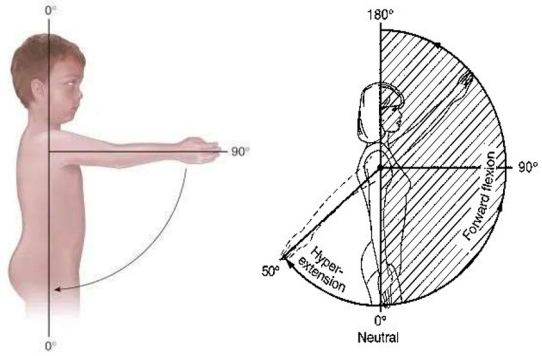
Students work assembling study chairs on assembly workstations. Students' duties include reading instruction sheets and blueprints on assembling parts, retrieving study chair components, and using power tools to assemble parts and materials correctly. The hand grip support provides firm support and facilitates a better wrist, as shown in Figure 2.

Fig. 2. A student assembles a study chair at the workstation facility before redesigning and supporting the use of an electric

A cordless electric screwdriver and portable, voltage 4.8 V, battery 600mAh NI-CD, no-load speed 180 rpm, torque 2.6 Nm, screwdriver bit size 6.35 mm. A cordless electric screwdriver and portable, voltage 4.8 V, battery 600mAh NICD, no-load speed 180 rpm, torque 2.6 Nm, screwdriver bit size 6.35 mm. The activation mode of this cordless screwdriver is trigger-to-start by pressing the trigger lever, and each participant is asked to activate it using only his right index finger.

2.4 Experiment design

Measure muscle strength using HHD mounted on a pedestal to measure isometric muscle moments. Muscle strength as force (N) and breakdown of the individual lever arm between the dynamometer and the center of the joint. Because the length of the operating lever arm will differ depending on the anthropometric and will affect the amount of force read on the HDD, the value of the strength data at the joint moment is obtained in this way. The amount of muscle strength, including moment fair and moment maximum, is obtained according to the ROM data at the upper limb joint. Arm muscle strength was tested through the reach of the shoulder joint in the sagittal plane in a 90° forward flexion position with the arms straight forward [22],[23],[24], as shown in Figure 3. Maximum isometric contractions were performed for 3 seconds each, with a rest period of 15 seconds between successive contractions. Before testing, a sub-maximal practice trial was conducted, and a 60-second rest period was provided between trials. The maximum value of the two trials was used in the analysis.



(a) (b)

Fig. 3. (a) Shoulder flexion is initiated from the anatomical position. (b) ROM in flexion moves anteriorly from the zero position through the arc to 180° measured in goniometry

2.5 Kinematics testing

The testing is assembling a study chair at the assembly workstation before and after the redesign by comparing the values of the moment fair and moment maximum at the shoulder and elbow joints. A natural moment is a static muscle moment to support a segment against gravity. Moment maximum is the moment maximum of static muscle against gravity. This paper discusses installing and tightening bolts on a study chair at workstation facilities, which is measured using a kinetics analysis. Calculating the value of the fair and maximum moment refers to the ROM, as shown in Figure 4.

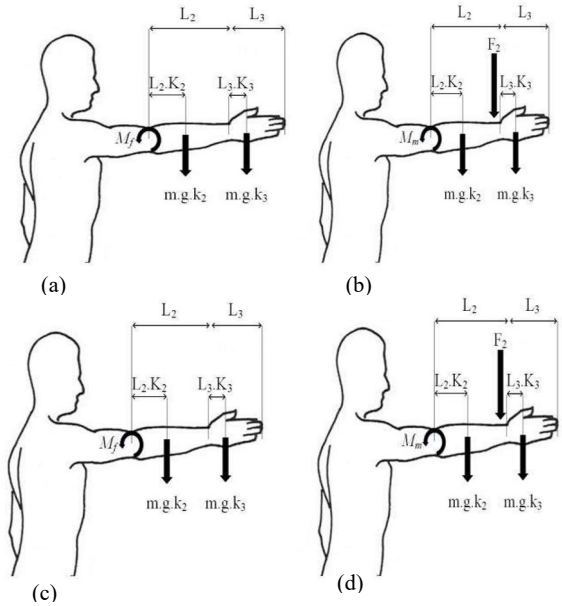


Fig. 4. (a) Mf on the shoulder joint, (b) Mm on the shoulder joint, (c) Mf on the elbow joint, (d) Mm on the elbow joint

Mf = Moment fair (N.m)
Mm = Moment maximum (N.m)
k1 = Upper arm segment weight factor
k2 = Forearm segment weight factor
k3 = Hand segment weight factor
K1 = Upper arm segment center of gravity distance ratio
K2 = Distance ratio of the center of gravity of the forearm segment (cm)
K3 = Distance ratio of the center of gravity of the hand segment (cm)
L1 = Length of upper arm segment (m)
L2 = Length of forearm segment (m)
L3 = Length of hand segment (m)
m = Body mass (kg)
g = Gravitational acceleration (m/s^2)
sinα = Corner of the shoulder joint (^{o})
sinβ = Angle of the elbow joint (^{o})
F1 = Maximum resistance in the upper arm segment (N)
F2 = Maximum resistance in the forearm segment (N)

Arm length (distance between the fingertips and shoulder joint) divided into the upper arm, forearm, and hand segments must be measured before adjusting position measurements. The HHD is zeroed from this state, and the maximum muscle strength (Force, F) is measured when performing an isometric muscle contraction at maximum effort for each movement. In addition, various arm position movements are practiced before measuring, and the ability to perform them correctly is confirmed, and adequate rest is taken to reduce the effects of fatigue. F was measured twice for the four experimental repetition tasks, and the mean was considered a representative value. Body weight (BW), which is required to calculate the theoretical Grade 4 muscle strength value, was also measured. After taking measurements, the theoretical Grade 4 muscle strength value (moment fair, or Mf) and the maximum muscle strength value (moment max, or Mm) in MMT.

The value of fair and maximum moment in the kinetics analysis of upper limbs obtained equations is:

- Moment fair (Mf) on the shoulder joint

$$Mf = m.g.\sin\alpha((k_1L_1K_1)+\left(\sin(180\text{-}\beta).\left(\left(k_2(L_1+(L_2K_2)\right)\right)+\left(k_3\left(L_1+L_2+(L_3K_3)\right)\right)\right)\right) \quad (1)$$

- Moment fair (Mf) on the elbow joint

$$Mf = m.g.\sin(180\text{-}\beta).((k_2L_2K_2) + (k_3\left(L_2+(L_3K_3)\right))) \quad (2)$$

- Moment maximum (Mm) in the shoulder joint

$$Mm = Mf+(L_1F_1) \quad (3)$$

- Moment maximum (Mm) in the elbow joint

$$Mm = Mf+(L_2F_2) \quad (4)$$

2.6 Statistical analysis

Two kinematics models were compared statistically, including moment fair and moment maximum, and before and after redesigning a study chair assembly workstation facility. Our data were analyzed using a paired t-test (Paired Samples t-test) [25]. Statistical significance was set at $p < 0.05$, and the below-reported differences in results were statistically significant unless otherwise stated. Data are presented as mean ± standard deviation (SD).

3 Result and discussion

Student characteristics data from 20 males and right-handed dominant, where age ($p = 0.063$) and hand dominance ($p = 0.78$) showed no significant differences between students in kinetics except for peak hand velocity and arm abduction. Before the measurement data is analyzed further, it is necessary to test hypotheses, including a normality test and a homogeneity test of the data using SPSS, IBM software version 20, to determine whether the data is normally distributed and homogeneous.

The normality test of the data used the Kolmogorof Smirnov test if the p-value was more significant than 0.05. The normality test results on muscle strength data on all students obtained that all data had a significant value of more than the p-value of 0.05. Then, the data was declared to be normally distributed. Test the homogeneity of the data using Lavene's test if the p-value is above 0.05. Data on muscle strength in all students obtained that all data had a significant value of more than the p-value of 0.05, and then the data was

declared homogeneous. This means that the measurement data are reported to be normally distributed and homogeneous and meet the requirements for further analysis.

The analysis of the Kinect SDK sensor and the supporting LightBuzz Vitruvius software present angle data from the ROM from reading the skeleton diagram direction in real-time. The measured data verify whether the sensor is suitable for identifying student movement while performing assembly tasks. The application of the Kinect SDK sensor as a depth sensor is assessed so that the accuracy and precision of the data obtained by the Kinect depth sensor meet the requirements for measurement.

The Kinect SDK sensor has a digital camera with a resolution of 640x480 pixels and a depth range sensor with a point gain of 320x240. Notably, in the RBG image and the depth data registration, the pixels provided in this image represent the same spatial point. The occlusion points were identified during movement, assisted by the LightBuzz Vitruvius software for angle estimation in the 3D position of these points through triangulation. Tracking techniques are used for student movement analysis and identification of point tracks associated with points in the kinematics model or dynamically. The points identified were extracted from a time sequence of 2D images using digital processing, such as pattern recognition and segmentation, as shown in Figure 5.

Fig. 5. Registration allows the identification point of a student when assembling to be recognized in the RGB image and its 3D coordinates to be extracted from the equivalence point of the depth data.

Twenty students involved male LPPD student assistants as experiment activity participants. All participants performed four repetitions using their dominant arm for coordination-based tasks, where arm position and direction of muscle strength varied for the shoulder rotator muscles. The order of execution to the experiment was randomized, and the maximum external load (an electric screw-driver powered) corresponded to 2% of the student's body weight. Experimental measurement results are described in Table 1.

The effect of ROM on the shoulder and elbow joint based on the average measurement results on the student when using the assembly workstation facility shows the average difference between the workstation before the redesign and the workstation after the restoration. ROM for flexion/extension and adduction/abduction affects the angle of the upper limb of a student when assembling a study chair.

Table 1. The results of measuring fair and maximum moment of 20 students with four repetitions at a study chair assembly workstation facility

Test	Joint	Assembly Workstation Facilities	Mean±SD (N.m)
Moment Fair	Shoulder Joint	Workstation before redesign	7.65±0.93
		Workstation after redesign	5.06±0.61
	Elbow Joint	Workstation before redesign	3.49±0.35
		Workstation after redesign	3.10±0.45
Moment Maximum	Shoulder Joint	Workstation before redesign	57.01±3.23
		Workstation after redesign	53.53±3.32
	Elbow Joint	Workstation before redesign	39.87±3.11
		Workstation after redesign	36.79±2.63

Although no statistical analysis was carried out for ROM, the maximum ROM was achieved when a student between the shoulder angle and the elbow was parallel or 90º. Two kinetics, fair and maximum moment at the workstation before a redesign, show a higher average value. These different moments in each student may occur because of the different movement patterns in the two joints. The change in the joint moment between the shoulder and elbow joint indicates that the moment maximum must be considered when selecting an appropriate assembly workstation facility. This shows that the improvement in the workstation after the redesign provides work comfort for the student. Work posture for students is important in the comfort analysis because it considers the effects of body segments and perceived effects in evaluating the position of maximum comfort. Comfort evaluation measures the ROM at each joint as the limit of variability and mobility to fair and maximum moment.

The Kinect SDK sensor devices and LightBuzz Vitruvius software are used to measure a student in assembling a study chair at a workstation facility. Table 2 explains that measurements at the shoulder and elbow joints showed that the wrist experienced less extension and flexion when working with an electric screwdriver between the shoulder and elbow joints at the workstation facility before the redesign.

Table 2. The results of the paired t-test on the fair and maximum moment on the shoulder and elbow joints at a study chair assembly workstation facility

Test	Joint	Assembly Workstation Facilities	N	Mean±SD (N.m)	Diff. Mean	*t*-value	*p*-*value*
Moment Fair	Shoulder Joint	Workstation before redesign	20	7.65±0.93	2.70 (35%)	14.00	0.001
		Workstation after redesign	20	5.06±0.61			
	Elbow Joint	Workstation before redesign	20	3.49±0.35	0.39 (11%)	4.55	0.001
		Workstation after redesign	20	3.10±0.45			
Moment Maximum	Shoulder Joint	Workstation before redesign	20	57.01±3.2	3.48 (6%)	4.51	0.001
		Workstation after redesign	20	53.53±3.3			
	Elbow Joint	Workstation before redesign	20	39.87±3.1	3.07 (8%)	5.38	0.001
		Workstation after redesign	20	36.79±2.6			

The results of the paired t-test to determine the difference in workstation facilities before and after redesigns to the position of the shoulder and elbow joints with measurements at fair and maximum moments showed significant differences ($p < 0.05$) with p-value = 0.0001. This is due to the relatively fixed position of an electric screwdriver powered during horizontal movement. In contrast, the ulnar deviation and radial deviation were lower when using the workstation facility after a redesign, which could be attributed to more hand movement in the vertical direction. These results are consistent with the findings of Naddeo et al., who reported higher wrist extension and flexion when working with an electric screwdriver powered while using a workstation facility before redesign [26].

After a redesign, the results showed that a student was more comfortable assembling a study chair at a workstation facility ($p < 0.05$). However, when assembling, a student using a powered electric screwdriver with a work posture is more comfortable, especially for the hand/wrist. Overall, the comfort assessment toward work student posture shows that it uses the workstation facilities after redesigns with the ability to rotate the table where the fixture rotates as far as 360o is more comfortable due to using metal square plate swivel bracket components than a placon roller. The study by Naddeo et al. [12],[26] also reported that the comfort parameter would gradually improve when users get used to working with an electric screwdriver powered with a study chair assembly workstation after a redesign. Therefore, after a redesign, students become more comfortable using this device when they get used to working with an electric screwdriver in a study chair assembly workstation.

4 Conclusion

The MMT method predicts the muscle strength at the fair and maximum moments with a kinetics formula derived from the theoretical Grade 4 assessment in MMT in shoulder and elbow flexion/extension tasks. The Kinect SDK sensor and LightBuzz Vitruvius software generate accurate and easy data to support decision-making in evaluating comfort students with work posture when assembling a study chair. In this study, the range of articular motion and posture that a student's body can accept for each joint, ROM, is divided into angular range, where a student feels postural comfort at the workstation facility after a redesign.

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