assembly tasks. This method is time consuming because it requires an always available instructor for the student. The instructional manual used as a teaching aids will actually capture only specific tasks, regularly in an incomplete way and can be an error prone process. The traditional assembly instruction may contain unimportant information about assembly that can result in misinterpretation, especially for novice user who has no or limited experience. Furthermore, the number of errors in assembly process can increase. Thus, this will cause work takes longer time to complete [1].

The teaching method on assembly task can be shortened and done with less need of instructor by relying on the technology that are able to convey the knowledge more effectively using step by step instructions containing virtual information like 3-Dimensional (3D) object. A new technology for assembly training education, which is deliberated in numerous studies, is Augmented Reality (AR). AR have been recommended for their massive potential to facilitate better comprehension [2][3]. AR claims to increase the efficiency of assembly task by directly visualizing computer generated 3D information in the real environment [4]. AR also allows to display the assembly instruction in real time so it is always relevant to the situation [5] without having to change the user attention to figure out the next step [6]. However, there are still unsolved issues that overshadow AR benefits especially in assembly education. The studies of AR impact in field of assembly task, such as error rate reduction and a shorten of time completion particularly in personal computer (pc) assembly are still few. Therefore, this paper aims to investigate the impact of AR towards the time of task completion and the error rate made during the assembly task

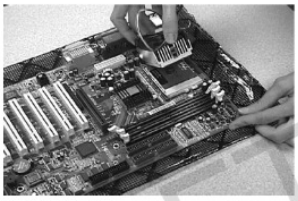
II. Related Works

This section will discuss on the related works that focus on the assembly process and the use of AR in assembly task.

A. 2D Assembly Manual

Assembly is a process or action fitting together the component part of a machine or other object. For example, to achieve a simple goal of placing a peg in a hole, there are some factor to be consider such as the technique to hold the peg, determining the position peg and hole and inserting the peg into the right hole. Each of the step and action require differ cognitive activity thus it demands a visual guidance to ensure the right result. Presently, 2D assembly manual has been utilized as the main visualization means to guide assembly in many sectors including in education. Student perform the practical session such as assembly task or laboratory activities by using 2D manual instruction. Fig. 1 is the example of assembly instruction used in practical session in computer course.

This manual contain text and graphic only to represent the process on how to complete the task. In addition, this instructional manual contains unnecessary information or unclear figure. This might confuse the user where user need to focus the important information in order to complete the task. As a result, this has impacted the time to complete the work become longer.



Follow these instructions for CPU and heat sink/fan assembly installation:

Step 1. Align the CPU so that the Connection 1 indicator is lined up with Pin 1 on the CPU socket. Doing this ensures that the orientation notches on the CPU are aligned with the orientation keys on the CPU socket.

Step 2. Place the CPU gently into the socket.

Step 3. Close the CPU load plate and secure it in place by closing the load lever and moving it under the load lever retention tab.

Step 4. Apply a small amount of thermal compound to the CPU and spread it evenly. Follow the application instructions provided by the manufacturer.

Step 5. Align the heat sink/fan assembly retainers with the holes on the motherboard.

Step 6. Place the heat sink/fan assembly onto the CPU socket, being careful not to pinch the CPU fan wires.

Step 7. Tighten the heat sink/fan assembly retainers to secure the assembly in place.

Step 8. Connect the heat sink/fan assembly power cable to the header on the motherboard.

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Fig. 1 Example of assembly manual

B. AR in Assembly or Maintenance Task

AR application have been applied within the industrial phases, ranging from the design [7], planning phase, to the training and guidance [8] of the workforce that will be assembling for the product [9]. The current status of AR applications in assembly task generally have been reviewed by reference [10]. However, there are still some parts that need further investigations.

Reference [11] conducted a study to compare an AR tablet-based solution with written instructions involving seventeen students as participants. The students maintained a 737 Engine Bleed Air System with the support of either a tablet or written instructions. The results showed that AR can improve a time 17% and 24% quality increasement. Another study [12] focused on the comparison between AR and paper-based instruction. Forty volunteers were participated in the study where they were divided into twenty volunteers assemble a gully trap with the support of paper-based instruction. While another twenty volunteers assembled the same task using AR. The findings indicate that the participants learn 43% faster when using AR.

Reference [13] measured the impact of a video-see through solution (Oculus-Rift and HMD camera) and face-to-face training towards trainee's knowledge retention. The participants consisted of twenty-four volunteers, divided into twelve each group based on the treatment. They had to learn on a maintenance task of an aircraft door. The findings showed that trainee spent more time to complete the task when using video-see through and the analysis proved that there was no significant difference for the knowledge retention test and knowledge interpretation test between the two conditions.

In [14] study, they performed an experiment involving a monitor-based system with seven engineering students as participant. The task employed in this study was an assembly task of 12 parts of an aircraft. The results indicated that AR instruction help to reduce the assembly time compared to conventional manual. Another study [15] compare the knowledge retention among participant who went through either traditional AR with step-by-step guidance or intelligent AR system which prompt feedback to the users. There were sixteen participants involved in this study where they need to assemble five motherboard components. The

finding shows that there were no significant differences in error rate or time of completion between the two conditions. Further analysis reveals that participant who used intelligent AR systems score 25% higher in knowledge retention.

Reference [16] has developed an AR application to assist in assembly and inspection of pipe spools. Twenty-one professional pipe fitters and forty engineering students were participated in this study. They were asked to assemble a complex pipe spool using either conventional or AR approach. Further statistical tests revealed that AR can aid save substantial time in assemble the pipe spool compared to conventional approaches. There is wide literature on AR applications for training or assembly task. However, there is only a few publications was found on applications developed for pc assembly

III. Methodology

The methodology used in this section aim to achieve the objective stated earlier.

A. User Study Design

In this study, to be able to measure the benefits of using AR, it was imperative to compare it with the conventional instructions. Therefore, the AR application developed in this study is used in a comparative between-subject user study to compare the AR assembly instruction (experimental group) with the conventional assembly instruction (control group). The comparative user study was quantitative and focused on pc assembly task.

B. Participants

A total of 18 users, with an age ranging from 18 to 20, participated in the test. Most of them were Information Technology and Communication students. This study involved two groups: Group 1-Control Group: participants performed the pc assembly task using the manual instruction (conventional method). Group 2-Experimental Group: participants performed the pc assembly task using the Augmented Reality application (AR method).

C. Instruments

Two types of measurement were taken: task completion time and error rate. Task completion time is defined as time of completion of the assembly task. Time of completion is the measurement of time to complete performing all the procedure of assemble a computer. While error rate is a number of errors detected after the pc assembly process completion.

A marker-based application using AR technology, namely AR PC Application has been developed. It is a AR book-based educational tool that contain an instruction with step by step to assemble a pc. There are AR markers inside the book where when users scan on it, it will allow overlaying layers of virtual information on real scene with the goal of increasing the perception the user has of reality. Fig. 2 (a), (b) and (c) show the screenshot of AR PC Application.

The Application consist of 4 main menus as shown in Fig. 2 (a). The Assembly menu consist sub-menu as shown in Fig. 2 (b). Figure 2(b) show the sub menus when the button PC assembly is pressed. There are six sub menus include: motherboard, CPU, heat sink, memory card, internal drive, power supply and cable. Fig. 2(c) show the images when user played the button. User need scan on the marker, and the assembly video will be played in real time as virtual object. User can press play and pause button while the video is playing. Help menu consist of 2 sub menu which is pc assembly tips that give the do and don'ts when assembling the pc. Meanwhile user guide, provide user the manual on how to use the apps. Finally, About menu contain info about the developer.

a

b

c

Fig. 2(a) Main Menu; (b)Submenu for Assembly; (c) Screenshot video in 3D

D. Procedures

The participants in both group were provided with the hands on activity on assemble a pc, where they were required to complete the assembly task based on the instruction presented using the specific medium as per the appropriate treatment. The participants completed the experiment with either: (1) perform an assembling task using conventional method (Control Group), or (2) perform an assembling task using AR application which provide a real time virtual object as a visualization (Experimental Group). Both groups followed the same protocol and were instructed to complete the same assembly task.

Next process is where theoretical concept was provided by the lecturer in the classroom where computer assembly course was implemented. After the theory class, each subject performs the assembly task based on the assigned method. During the two-week application period, the control group students conducted their lab in pc assembly using the traditional instructional manuals and under the supervision of the lecturer. On the other hand, the experimental group conducted the pc assembly lab using augmented reality application namely AR PC Assembly under supervision the same lecturer. After the treatment, the time and the amount of errors were noted.

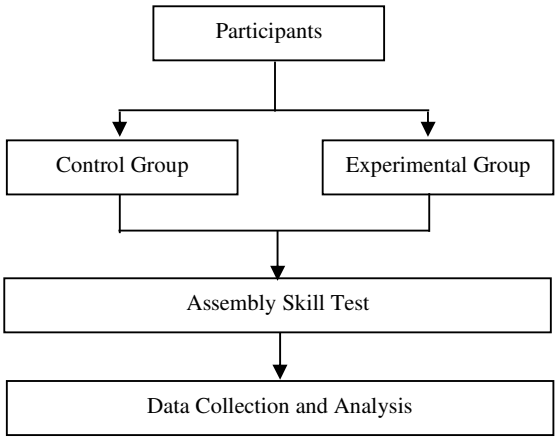

Fig. 3 Research Procedure

IV. Data Analysis and Result

The findings were divided into two part which are on the time completion and error rate.

A. *Time Completion*

To investigate whether the use of AR application has an impact on time to complete the assembly process, the descriptive and inferential analysis was performed. An average time to complete the task by student in each group was analysed and presented in Fig. 4. As illustrated, experimental group has a shorter time to complete the assembly task (18 minute) compared to control group (24 minute).

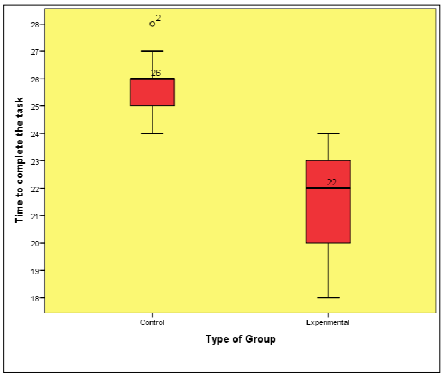

Fig. 4 Average Time of Completing PC Assembly

Fig. 4 shows the boxplot of time to complete the task by group, where the median time to complete the task was 26 minutes for control group and 22 minutes for experimental group. In control group, mostly student complete the task within 25 minute and 26 minutes but most student complete the task as faster as 24 minute and as slower as 27 minutes. Outlier data found in control group which is at 28 minutes indicate that the value was extremely higher in the whisker. Compared to experimental group, the median time was recorded as 22 minutes, where most student complete performing the task within 20 minute and 23 minutes. Most student can complete the task as faster as 18 minute and as slower as 24 minutes.

TABLE I
T-Test Result for Time to Complete the Task

		t	*df*	Sig (2 tailed)	Mean Diff	Std.Dif
Assemble Time	Equal variance assumed	5.714	16	.000	4.444	.778
	Equal variance not assume	5.714	13.11	.000	4.444	.778

Independent t-test was performed to compare the time of completion for two different group. According to the result as shown in Table I, the average time of completion depending on the instructional used (manual instruction and AR Application) is statistically significant, t (16) =5.714, p value < 0.01. Hence, this result suggests that using AR can shorten the duration of completing the assembly task when compared to the traditional instruction manual.

B. *Error Rate*

Another dependent variable collected in this experiment is the number of error and type of error made when assembling the pc. Table II describe the type of error, number of student for each group and the total number of error made.

TABLE II
Error Description and Number of Error

Error Type	Control Group	Experimental Group
Install CPU wrong	2	1
Installing the RAM wrong way	2	1
Installing graphic card in wrong slot	3	1
Not connecting front I/O panel	4	2
Plugin the cable to wrong source	3	2
Total	14	7

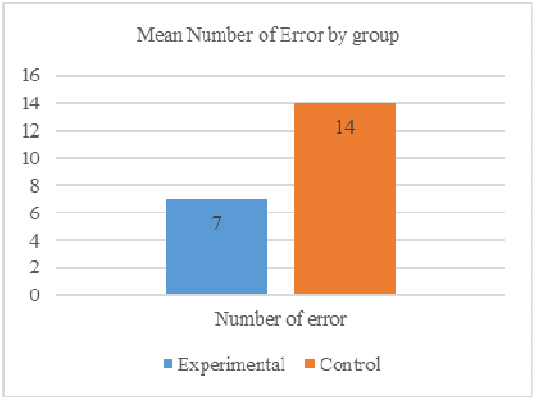

Fig. 5 Mean number of error by group

Fig. 5 point out the average number of errors in order to complete the pc assembly task. It is apparent from this figure

that in experimental group, participants had a lower average error rate compared to traditional treatment which is 7 and 14 respectively. Additionally, Fig. 6 summarize the error made by group.

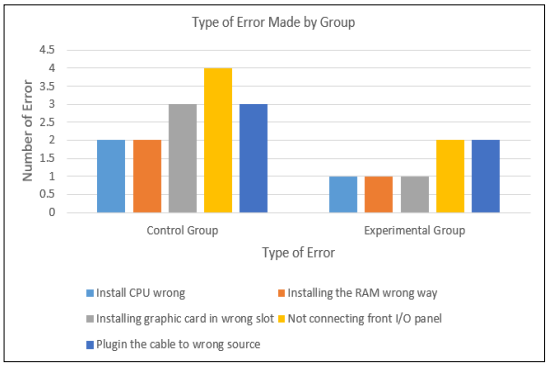

Fig. 6 Summary of error made by group

Table III provides the t-test result of error made in both groups. It can be seen from the data in table that the average number of errors depending on individual intervention received (instructional manual and AR Instructional) is statistically significant, t (1, 16) =3.395 where p value=0.04. Therefore, AR appears to have an advantage in reducing error, compared to the traditional method.

V. Discussion

Prior studies have noted the importance of integrating AR in training and maintenance sectors. Yet, there are some inconsistent in findings in several reports.

This study set out with the aim of assessing the importance of AR in assembly task specifically focused on the time of completion and the number of errors. The current study found that the developed AR application help in shortening the time to complete the assembly task and reduce the number of errors made during the process compared to conventional manual.

TABLE III
T-Test Result of Error Made

		t-test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Error Made	Equal variances assumed	3.39	16	.004	.778	.229	.292	1.263
	Equal variances not assumed	3.35	15.7	.004	.778	.229	.291	1.265

These results reflect those of [15] who also found that AR technology can facilitate the learner to assemble motherboard faster and fewer mistakes. This finding was also reported by [17] which revealed that by letting users view the overlaying components and instructions through AR can reduces the number of errors, which in turn allow them to easily troubleshoot task. This finding is important as it serve as a support that AR is a suitable instructional in assembly task.

This result may be explained by the fact that the reduced number of head, eye and body movement that student need to go through to read the instruction, has reduced the number of error made. This is because student no need to memories the instruction, performed the assembly task, look back at the instructional to recheck and confirmed the step. By using AR application, student has better visualization on how to perform the step and they just do it without need to take a longer time to understand the instruction. Therefore, the time to complete the task can be reduced as well as the error.

By using AR Application, it provides animation that dynamically demonstrated the assemble process. This is because student can imitate the assembly step and compete the process in ease. AR technology has been repeatedly shown increase the education and training through interactivity and visualization. AR can provide instinctive interaction experience to the user by combining the real word with various computer-generated content. The strength of this study was the successfully development of the AR PC Assembly Application and its implementation by providing an engaging and effective tool in assembly task. AR PC Assembly Application was developed by following some guideline in Universal Design of Learning (UDL).

According to reference [18], the following principle was suggested in order to establish learning environment for all: (1) Provide multiple means of representation.

In this context, flexible options for the presentation of content has been highlight. In AR PC Assembly, the information was presented by using button, icon, text, images and video. There are four modules in this application namely introduction, pc assembly, help and contact us. (2) Provide multiple means of action and expression.

This guideline refers to how learning in being presented. For example, in AR PC Assembly application, the content uses multiple media for communication, such as HELP menu where user read by their own and video that played automatically when detect the marker. (3) Provide multiple mean of engagement. This guideline refers to how to engage and collaborate the user to the system. In AR PC Assembly, even though there is no self – evaluation, but user do engage with the application because the method of to play the video, user has to scan the marker. Therefore, user need to focus thus this encourage the user to complete the assembly task. AR PC Assembly has offered a simple design and content has make the application more accessible and easier to use even to novice user. Hence, this one of the factors that contribute to the positive result in this study.

VI. CONCLUSION

The purpose of the current study was to determine the impact of AR towards the time of task completion and the error rate made during the assembly task. This study has found that generally the time to complete the task were shortening and fewer error or mistake made during the assembly process in AR assisted system group than manual instruction. Overall, this study strengthens the idea that AR can potentially improve the process of training, assembling and troubleshooting of the pc by displaying directly the information to the user. This work contributes to existing knowledge of AR in assembly by providing a deeper insight into the application of AR in reducing the time completion and error specifically in pc assembly. The generalizability of these results is subject to certain limitations. For instance, the small sample size did not allow for more generalization of the findings. Large samples size in future work could provide more definitive evidence for this impact

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REFERENCES

[1] Z. Michael F., and M. Wiesbeck, "A model for adaptively generating assembly instructions using state-based graphs." *In Manufacturing systems and technologies for the new frontier*, pp. 195-198. Springer, London, 2008.

[2] D. N. E, Phon, M.H.A. Rahman, S. Hashim, N.F Jumaat, W. I. S. W, Din, S.M. Asmara, "Exploring The Student's Interaction with Augmented Reality and Their Relationship to Learning Achievement". *International Journal of Advanced Science and Technology*, vol. 28, no. 2, pp. 301-307, 2019.

[3] D. N. E., Phon, A. F. Z. Abidin, M. F. Razak, S. Kasim, A. H. Basori, & T. Sutikno, T., "Augmented reality: effect on conceptual change of scientific". *Bulletin of Electrical Engineering and Informatics*, vol.8, no.4, 1537-1544, 2019.

[4] S. Werrlich, E. Eichstetter, K. Nitsche, G. Notni, "An overview of evaluations using augmented reality for assembly training tasks", *International Journal of Computer and Information Engineering*. 11(10):1068-74, 2017.

[5] N. Gavish, T. Gutiérrez, S. Webel, J. Rodríguez, M. Peveri, U. Bockholt, F. Tecchia, "Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks". *Interactive Learning Environments*. 23(6):778-98, 2015.

[6] X. Wang, SK. Ong, AY. Nee. "A comprehensive survey of augmented reality assembly research". *Advances in Manufacturing*. 4(1):1-22, 2016.

[7] S. Alsafouri, & S.K. Ayer, "Mobile Augmented Reality to Influence Design and Constructability Review Sessions", *Journal of Architectural Engineering*, 25(3), 2019.

[8] T. Bosch, G. van Rhijn, F. Krause, R. Könemann, E. S Wilschut, & M. de Looze, "Spatial augmented reality: a tool for operator guidance and training evaluated in five industrial case studies", *In Proceedings of the 13th ACM International Conference on PErvasive Technologies Related to Assistive Environments* (pp. 1-7). June 2020.

[9] L. Xia, J. Lu, Z. Zhang, R. Chen, S. Wang, & H. Zhang, "Development and Application of Parts Assembly Guidance System Based on Augmented Reality". *In 2019 IEEE 4th Advanced Information Technology, Electronic and Automation Control Conference (IAEAC)* (Vol. 1, pp. 1325-1330). IEEE, 2019.

[10] X. Wang, S. K. Ong, A. Y. C. Nee. A comprehensive survey of augmented reality assembly research. *Adv. Manuf.* 4(1), 1–22, 2016.

[11] H. Rios, E. González, C. Rodriguez, H. R. Siller, and M. Contero, "A mobile solution to enhance training and execution of troubleshooting techniques of the engine air bleed system on Boeing 737". *Procedia Computer Science*, 25, pp.161-170, 2013.

[12] P. Hořejší, "Augmented reality system for virtual training of parts assembly". *Procedia Engineering*, 100(January), 699-706, 2015.

[13] M. Gonzalez-Franco, R. Pizarro, J. Cermeron., K. Li, J. Thorn, Hutabarat, W., Tiwari, A. and P. Bermell-Garcia, P., "Immersive mixed reality for manufacturing training". *Frontiers in Robotics and AI*, 4, p.3, 2017.

[14] F. Suárez-Warden, E.G. Mendívil, C.A Rodríguez, and S. Garcia-Lumbreras, "Assembly operations aided by augmented reality: an endeavour toward a comparative analysis". *Procedia Computer Science*, 75, pp.281-290, 2015.

[15] G. Westerfield, A. Mitrovic, and M. Billinghurst, M. "Intelligent augmented reality training for motherboard assembly". *International Journal of Artificial Intelligence in Education*, 25(1), pp.157-172, 2015

[16] C. M. Kwiatek, S. Li, Sharif, C. Haas, and S. Walbridge. "Impact of augmented reality and spatial cognition on assembly in construction." *Automation in Construction* 108 (2019): 102935.

[17] A. Bellucci A., A. Ruiz, P. Díaz P., I. Aedo. "Investigating augmented reality support for novice users in circuit prototyping". *In Conference on Advanced Visual Interfaces,* AVI'18 pp. 35:1–35:5, 2018.

[18] M. T. Leinenbach, & M. L Corey, "Universal design for learning: Theory and practice. In Society for Information Technology & Teacher Education". *International Conference Association for the Advancement of Computing in Education (AACE*), (pp. 4919-4926). 2004.