Usability Evaluation and User Acceptance of Cobot: Case Study of Universal Robots CB Series.

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Abstract

Cobots have been increasing its importance due to the new stage in the development of industrial robots, in which humans and robots will collaboratively operate tasks whenever and wherever possible. By integrating cobot to coworking with humans, it can increase the competitive advantages to the industry in term of flexibility, quality, and productivity. However, the quality of its interface plays crucial role since it requires more interactions between operator and cobot in completing the working tasks. Thus, the purpose of present study is to evaluate the usability of cobot's user interface and user acceptance of cobot, universal robots CB series. Twenty senior undergraduate students in industrial engineering participated in this study. These experiments were remote moderated experiment. All participants were trained by using original training materials (training VDO) of universal robots CB series before start using cobot in experiment. Testing task was to move box from point A to point B which is the basic task of cobot, this follows the VDO training instruction. During the experiment, occurred errors were counted (repeat count). After the testing task, participants were asked to evaluate the cobot's program interface using SUS questionnaire and user acceptance using TAM questionnaire. Results showed that only 10% of participants could successfully perform testing task using cobot interface. Major error found during participants worked with testing tasks were that participants created irrelevant commands. Participant's attitude toward cobot remained positive. Implication and suggestion are discussed.

Keywords
Usability evaluation, Human-robot interaction, Collaborative robots, Universal robot, User acceptance

1. Introduction
Human-robot collaboration is the major subject for the industrial revolution into industry 5.0 by improving its flexibility, quality, and productivity from industry 4.0 (Moeuf et al. 2018). This introduced the concept of cobot or collaborative robot into the advancement of industry since it reduces the limitation from both standalone robot and human workforce. Cobot could help reducing workspace, increasing product quality, and increasing productivity (Sowa et al. 2021; El Zaatari et al. 2019; Müller et al. 2016). Human and robot could collaborate whenever and wherever possible in work setting (Demir et al. 2019; Galin and Meshcheryakov 2019).

Cobots are increasing in trend of being adopted in industry with variety of models used in the market such as Universal Robots (UR), ABB's YuMi, and KUKA LBR iiwa (El Zaatari et al. 2019). However, the proportion of using cobot comparing to the traditional robot is relatively small. This revealed that the acceptance of cobot in industry is yet challenging. Hence, there remains a need to improve its system to better fit with working condition such as Cobot's sensor and gripper as well as cobot's user interface to be more intuitive (IFR 2020).

According to the levels of human-robot collaboration (HRC), there were 2 major levels of collaboration which are a low level of HRC and a high level of HRC (Michaelis et al. 2020; Christiernin 2017). A low level of HRC includes no collaboration (level 0) and stop/start (level 1). This no collaboration (level 0) is a traditional fence robot that execute activities in a separate workspace from humans. A level 1 stop/start is the condition that human and robot share their workspace, robot is always idle when the human is present, or humans are only capable of initiating, setting, and terminating processes. A high level of HRC includes interactive (level 2) and collaborative (level 3). Interactive (level 2) is the work condition that human and robot synchronously work in the same workspace where human worker can adjust the programming to the interactive robot while working with. Collaborative (level 3) is more advance from interactive level by robot can learn and adjust the path of movement by observing human actions for support working together. However, there were a few studies on levels of collaboration between operator/non-expert and cobot, the studies revealed that the current level of collaboration in industry was remaining in a low level of HRC (Michaelis et al. 2020; Schmidbauer et al. 2020; Ionescu and Schlund 2019). This highlighted the need to develop cobot interface to enhance and support work collaboration.

Cobot's user interface is also a critical differentiation between cobots and traditional robots (El Zaatari et al. 2019). Cobot's user interface play important role in determining success at work since it is a medium layer between user and cobot in communicate working information. Moreover, the key user of cobot may not be an expert in robotic programming, this is a challenging in the interface development for operators who are non-expert in robotic programming to be able to modify, create, and customize programs. However, owing to the novelty of the technology or a lack of sufficient programming abilities, industrial personnel may lack knowledge and confidence in this subject. As a result, the use of the cobot may cause worry and mental strain for the workers. This indicated that programming the robot through the interface is critical in human-cobot interaction (Chowdhury et al. 2020). Thus, this required the interface to be easy to use, safe, and error less. Thus, it is worth conducting usability evaluation of cobot's user interface to understand and provide key usage barrier for future research to improve the interface of use. Moreover, the usability improvement of the interface will allow an enhancement of the level of collaboration in the future.

Besides, the adoption of cobot in industry should also consider the operator's attitude toward cobot. Researchers found that the negative attitude of operators toward cobot could enhance the difficulty for firms in transitioning to use cobot in work setting (Demir et al. 2019). Attitude can influence information perception and affect the degree to which it is retained (Ekpete 2012), also that attitude affects persistence in learning and solving a problem while in use (Gomes and Mendes 2007) According to Technology Acceptance Model (TAM), people's attitude affects directly to the adoption and acceptance of technology. Operator's acceptance of technology has been identified as a critical prerequisite for continued use and success of such systems (Hasan and Ahmed .(2007

With all the foregoing, the importance of user interface usability and operator acceptance of technology are critical in deciding to adopt cobot in the industry. This study aims to evaluate the usability of cobot's user interface and user acceptance using case study of universal robots CB series which was the market leader model according to Sharma (2019). Key metrics used in usability evaluation are success rate, error analysis, and system usability scale. The usability results would be analyzed to provide the key usage barrier for future improvement together with the participants' attitude toward cobot after trial its interface.

2. Methods

2.1 Participants

Twenty Thai senior bachelor students participated in this study. Their age ranges from 21 - 22 years (M = 21.15, SD = 0.37). 65% are males. All participants are 4th year industrial engineering students which are non-expert in robotics and programming. Their average level of programming skills was 1.25 (SD = 1.02) from the scale of 0 to 4; 0 is unskillfulness and 4 is skillfulness. All participants are familiar with Microsoft Teams for more than 2 years using experiences.

2.2 Apparatus

Due to the COVID-19 situation, online remote moderated experiments were conducted via desktop version of Microsoft Teams. Internet connections were tested prior the experiment which required the speed to be greater than 40 Mbps. Microphone, camera, and audio devices were required to test sound quality prior the experiment. Cobot interface program of universal robots CB series on offline simulator version 3.15.4 for non-Linux computers was used in this study.

2.3 Training Material

Training material used in present study were the original free e-learning courses for UR-CB series provided by Universal Robot (link: https://academy.universal-robots.com/free-e-learning/cb3-e-learning/). This e-learning courses consist of chapter 1 to 5 that cover the topics for preparing a cobot to perform a basic pick and place task. Participants in present study were only required to study before performing the testing task for chapter 1, 2, 4, and 5 which is the topic of Features and terminology, How the robot works, Creating a program, Interaction with external devices, respectively. These e-learning would take an average time in total of 50 minutes to complete all 4 chapters required in present study.

2.4 Testing Task

The testing task used in usability evaluation was a basic pick and place task which is the same task as in the e-learning course. Participants were asked to control cobot to move a box from point A to point B using offline simulator program as shown in figure 1. The experimental conditions were:

- Starting from the interface of programming which is ready to use.
- Control cobot program to move a box from point A to point B.
- While gripping, it is necessary to wait 1 second for the gripper to work completely.
- Gripper is “tool_out [0]”.
- The gripper weight 0.6 kg., the box weight 1 kg (total payload is 1.6 kg.).

2.5 Measurement

2.5.1 Success rate

The Success rate metric was used in usability evaluation to assess the completeness of the testing task performed by participants. In UR CB series interface program version 3.15.4 as shown in Figure 2, there is a left side panel illustrates the order that user have been set during performing task. This robot program list is used for checking the completeness of the testing task to determine the success in performing task. To be success in testing task, the correct sequence of program structure, the correct settings follow to the specified conditions, proper movement as shown in Figure 2, then it would be considered as success in task.

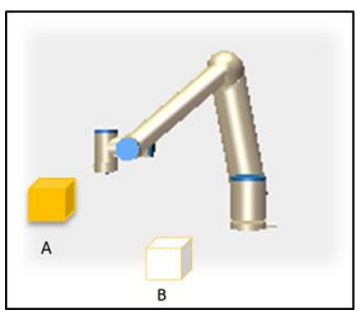


Figure 1. Basic Pick and Place task for usability evaluation.

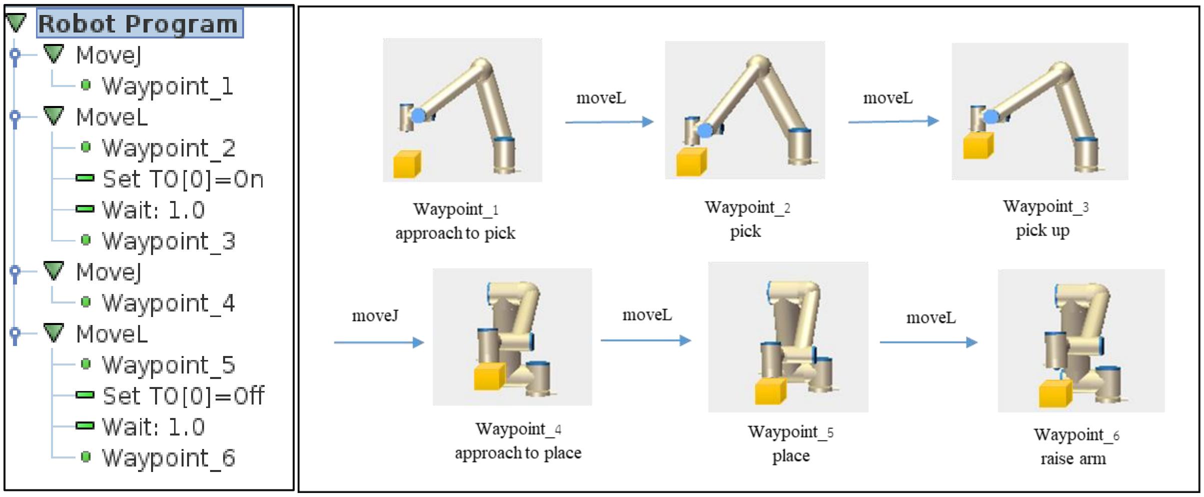


Figure 2. Solution of testing task: Program structure and simulation of proper movement

2.5.2 Error analysis

Error analysis metric was used in usability evaluation to assess the types and its frequency during participants performing the testing task. Error data were real time coded during the usability testing session. Error could be repeated within participant during coding.

2.5.3 System Usability Scale

The System Usability Scale (SUS) was used as a self-report metric in this study. SUS consists of a simple ten-questions to measure system satisfaction regarding its usability (Brooke 1996). Thai version of SUS was used in this study (Othatawong 2019). The SUS is evaluated using a five-point Likert scale which make the score ranges from 0 to 40. Then, the score would be converted from 0 to 40 into percentile (0 to 100) by multiplying 2.5. Percentile score of SUS could be used to compare with the standard of SUS score published by Sauro and Lewis (2012) for further analysis.

2.5.4 Technology Acceptance Model Questionnaire

Technology Acceptance Model (TAM) questionnaire was used to access participant’s attitude toward cobot (Lin 2013). TAM consists with 4 main parts: Perceived Ease of Use (PEU), Perceived Usefulness (PU), Attitude towards using (A), and Behavioral Intention to use (BI), using five-point Likert scale. Thai version of TAM was used in this study (Phongphaew 2016).

2.6 Procedure

The experiments were conducted with one participant at a time. Prior to begin the experiment, participants were explained the objective and brief description of the research, then were asked to read and sign a consent form to voluntary participate in the study. After signing a consent form, the internet connection speed was tested, and the quality of the audio, camera, and microphone were checked through online meeting session using Desktop version of Microsoft Teams. If everything is ready, then participants were asked to complete demographic questionnaire. During experiments, participants were asked to open their camera.

Participants watched the VDO introduction of UR CB series and then were asked to learn basic from e-learning courses for chapter 1, 2, 4, and 5. After finished all e-learning course, participants were explained the instruction of the testing task and the defined conditions. After confirmed their understanding, participants were shown the cobot program on the shared screen and then were asked to take control over the screen of cobot interface program to start the usability testing.

Once participants stated that they had completed the tasks or requested to stop the task, they were asked to evaluate the cobot’s interface of program by SUS questionnaire. Then, participants were explained task solution step by step. After that they were asked to rate TAM questionnaire, and then they were interviewed. After completed all the process, participants were thanked and dismissed.

3. Results

Results from usability evaluation and user acceptance test revealed key barriers that prevented user from successfully completing the testing task. Beginning with success rate metric, only 2 participants or only 10% of participants could complete the task, while other 4 participants resigned, and another 14 participants submitted incorrect answer. Then, the result of error analysis which were coded during the experiment for each session provided more details in what type of error occurred during the test and its frequency were reported in Figure 3. Top 5 Major error found during participants worked with testing tasks were that participants created irrelevant commands (40 times, 27% of recorded errors), wrong setting of movement in wait function (14 times, 9% of recorded errors), separate movement structures of the same type (13 time, 9% of recorded errors), setting the waypoint by moving the view for simulation of cobot (12 time, 8% of recorded errors), and lost on the welcome page before entering the homepage for programming (9 time, 6% of recorded errors), respectively.

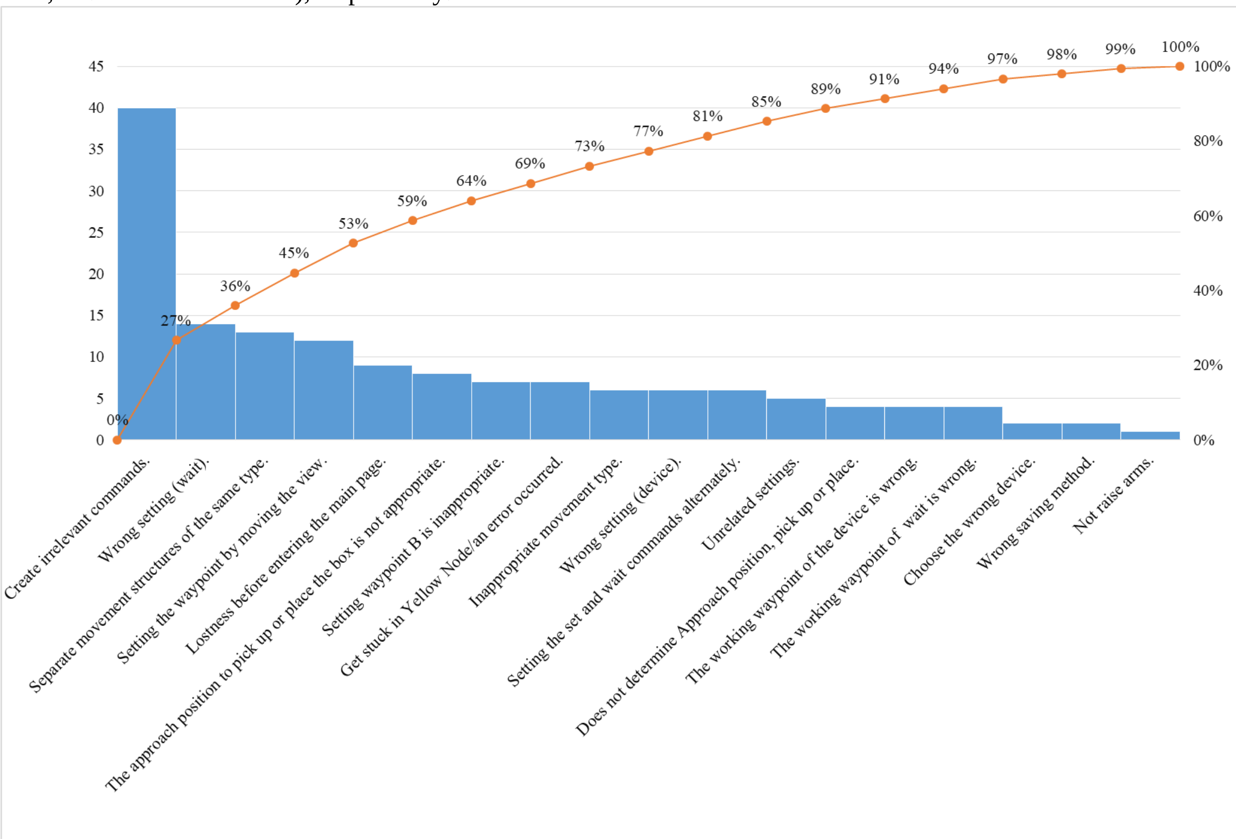


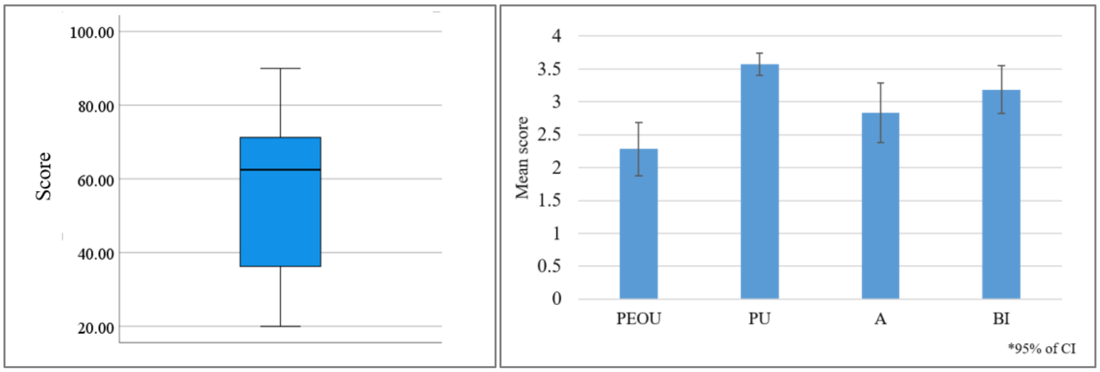
Figure 3. Error analysis by types and frequency of error occurred during experiment.

System Usability Scale questionnaire revealed the score ranged from 20 to 90 (M=57.625, SD=19.89, N=20) as shown in Figure 4(a). This could be interpreted as D grade according to the standard SUS score from Sauro and Lewis (2012) which is not accepted and may raise the need for improvement its interface. On the other hand, the results from TAM (Figure 4b) showed that the rating score of perceived ease of use (PEOU) is relatively low comparing with other 3 dimensions of TAM. This was correlate with the result from the usability testing. However, participants' attitude toward using and behavior intention remained positive.

There was some insight information regarding the current version of program interface from participants' interview after the usability testing. These were summarized as the following.

- Participants were confused by the word used in menu function at the welcome page between "Run program" and "Program robot".
- Participants reported that the position of the menu function in main page puzzled them so that they could not find the functions they were looking for.
- Participants' thought that the order of the program tab was inappropriate and inconvenient to use.

- The arrow function in move page was not practical due to their lack of understanding of the characteristics of the arrows. This made them unable to modify the proper direction of move the cobot's arm.
- Participants said that they were unrecognized that "SAVE" button could be pressed. This was why they could not find save button during testing.
- Position of functions on page were not standardize or clear edge of control on screen. It's difficult to find function or command they were looking for.



(a) (b)

Figure 4. Result from self-report questionnaire as (a) SUS boxplot and (b) mean score of TAM

4. Discussions and Conclusions

This study aims to evaluate the usability of cobot's user interface and user acceptance using case study of universal robots CB series. Participants were asked to perform task of controlling the cobot to pick and place after learning the original e-learning VDO. The results revealed some issues in interface design that caused very low success rate from participants. This indicated that the interface was not well-designed enough for those who are non-expert in robotics and programming or operators.

From the results of error analysis and user interview suggested that the structure or layout of the interface should be simplify in term of clear visual edge and be able to provide feedback for user so that they could recognize if there were any incorrect settings they have been made. Moreover, the terminology used for menu function should be user's language and not ambiguous. The errors reported in present study should be further investigated in detail. Cobot software designer may consider using usability iterative design process to get insight to the quality of the interface design for specific target user.

Additionally, SUS scores showed the result in the D grade of standard SUS usability. This reflected how participants perceived the usability performance of the system. The results from this study could be initially used to improve cobots' user interface and raised the need to concentrate on the quality of the technology interface. The creation of user interfaces are as equally as crucial to the improvement of safety and process of effectively organizing resources and labor (Aaltonen and Salmi 2019). Furthermore, it may influence to the adoption rate of user that is critical for the introductory phase of the technology.

On the same direction, user acceptance was accessed by using TAM questionnaire (Davis et al. 1989). Even though the overall attitude toward using was in the positive tone, the average rating scores of users' perceived ease of use was still being concerned. Participants' might have strong perceived usefulness from the technology of cobot, but the ease of use was a confirmed signaled that the usability issues of the interface were the barrier to adopt the cobot from user perspective. To support usability, the cobot's user interface should be developed to be more intuitive or providing adequate guidance for using it by their target user. This will increase the likelihood of new technology adoption in industry.

There were certain limitations to this study. Due to the severely spreading COVID-19 situation, so all experiments were remote moderated experiment. This may impact to the quality of participants' perception toward cobot comparing to the onsite experiment with the present of the physical cobot. Moreover, the time on task metric was not measured to avoid the bias of data recording in remote environment.

References

Aaltonen, I. and Salmi, T., Experiences and expectations of collaborative robots in industry and academia: barriers and development needs, *Procedia Manufacturing*, vol. 38, pp. 1151-1158, 2019.

Brooke, J., *Usability Evaluation in Industry*, Taylor and Francis, 1996.

Chowdhury, A., Ahtinen, A., Pieters, R. and Vaananen, K., User experience goals for designing industrial human-cobot collaboration: a case study of franka panda robot, *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society*, pp. 1-13, Tallinn, Estonia, October 25-29, 2020.

Christiernin, G., How to describe interaction with a collaborative robot, *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*, pp. 93-94, Vienna, Austria, March 6-9, 2017.

Davis, F., Bagozzi, R. and Warshaw, P., User acceptance of computer technology: a comparison of two theoretical models. *Management Science*, vol. 35, no. 8, pp. 982-1003, 1989.

Demir, K., Döven, G. and Sezen, B., Industry 5.0 and human-robot co-working, *Procedia Computer Science*, vol. 158, pp. 688-695, 2019.

Ekpete, O., Improving students' performance and attitudes towards chemistry through problem based solving techniques, *International journal of academic research in progressive education and development*, vol. 1, no. 1, pp. 167-174, 2012.

El Zaatari, S., Marei, M., Li, W. and Usman, Z., Cobot programming for collaborative industrial tasks: An overview, *Robotics and Autonomous Systems*, vol. 116, pp. 162-180, 2019.

Galin, R. and Meshcheryakov, R., Automation and robotics in the context of Industry 4.0: the shift to collaborative robots, *IOP Conference Series: Materials Science and Engineering*, Krasnoyarsk, Russian Federation, April 4-6, 2019.

Gomes, A. and Mendes, A., Learning to program - difficulties and solutions, *Conference: International Conference on Engineering Education*, Coimbra, Portugal, September 3-7, 2007.

Hasan, B. and Ahmed, M., Effects of interface style on user perceptions and behavioral intention to use computer systems. *Computers in Human Behavior*, vol. 23, pp. 3025-3037, 2007.

IFR., Demystifying collaborative industrial robots: position paper, *International Federation of Robotics*, Frankfurt, Germany, December, 2020.

Ionescu, T. and Schlund, S., A participatory programming podel for pemocratizing pobot pechnology in public and pndustrial pablabs, *Procedia CIRP*, vol. 81, pp. 93-98, 2019.

Lin, C.-C., Exploring the relationship between technology acceptance model and usability test. *Information Technology and Management*, vol 14, pp. 243-255, 2013.

Michaelis, J., Siebert-Evenstone, A., Shaffer, D. and Mutlu, B., Collaborative or simply uncaged? understanding human-cobot interactions in automation, *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, pp. 1-12, Honolulu, United States, April 25-30, 2020.

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S. and Barbaray, R., The industrial management of SMEs in the era of Industry 4.0, *International Journal of Production Research*, vol. 56, no. 3, pp. 1118-1136, 2018.

Müller, R., Vette, M. and Mailahn, O., Process-oriented task assignment for assembly processes with human-robot interaction, *Procedia CIRP*, vol. 44, pp. 210-215, 2016.

O-thatawong, P., User requirement and usability testing framework for information system development: case study of financial institution, (published master's dissertation), Chulalongkorn University, Bangkok, Thailand, 2019.

Phongphaew, N., The relationship between usability, technology acceptance model (TAM), and emotional responses on learning management system (LMS), (published master's dissertation), Chulalongkorn University, Bangkok, Thailand, 2016.

Sauro, J. and Lewis, J., *Quantifying the User Experience*, Morgan Kaufmann, 2012.

Schmidbauer, C., Komenda, T. and Schlund, S., Teaching cobots in learning factories – user and usability-driven implications, *Procedia Manufacturing*, vol. 45, pp. 398-404, 2020.

Sharma, A. Cobot market outlook still strong, says interact analysis. Available: https://www.roboticsbusinessreview.com/manufacturing/cobot-market-outlook-strong/. 18 July 2021.

Sowa, K., Przegalinska, A., and Ciechanowski, L., Cobots in knowledge work: human – ai collaboration in managerial professions, *Journal of Business Research*, vol. 125, pp. 135-142, 2021.

Biography

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