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Systematic Literature Review and Meta-Analysis of Microcontroller Learning Development in the Industry 4.0

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The ability to design and implement microcontroller-based systems is one of the skills and soft skills needed in Industry 4.0. Many researchers have identified various problems and have made solutions related to the learning process using microcontrollers, even though the names of the courses taught in the study programs at their respective universities are different. So a map of microcontroller learning problems and solutions that have been carried out by previous researchers is needed, then summarize and analyze them so that the core problems and solutions related to microcontroller learning in the Industry 4.0 era can be known. So in this study, we conducted a systematic literature review and meta-analysis of problems and solutions in microcontroller learning from research works on the Scopus database from 2019 to 2023, using the Watase UAKE application in which there is Prisma. The first stage carried out is the identification of studies on the Scopus database using several keyword variables that have been determined in advance, resulting in 173 articles. Then the first stage screening resulted in 78 articles, and continued with the second stage screening resulting in 36 articles. Retrieve articles that have DOI obtained 29 articles to be uploaded into the Watase database. Based on the results of data extraction and reading the contents of the article carefully, 20 articles were obtained that discussed the industry in the article, consisting of 13 qualitative research articles and 7 quantitative research articles. Only 7 quantitative research articles can proceed to the classification process stage of the meta-analysis. The results showed that the most popular learning method related to the learning process using microcontrollers in the Industry 4.0 era is the Project Based Learning (PBL) learning method.

Keywords: industry 4.0, meta analysis, microcontroller, systematic literature review, watase.

1. Introduction

The Industrial Revolution 4.0 has brought significant changes in various aspects of life, including education which requires the right curriculum design and learning methods to produce graduates who have the skills and soft skills to be ready to face the challenges and opportunities in the industry(Somasundaram et al., 2020). In the current Industrial Revolution 4.0 or Industry 4.0 leads to the era of digitalization such as business models, environments, production systems, operator machines, products and services that are interconnected in the digital world with appropriate virtual representations (Alcácer & Cruz-Machado, 2019). The use of information and communication technology is a very important requirement in the Industry 4.0 era, defined as data processing and dissemination technology using hardware and software, computers, communications, and digital electronics. The development of increasingly intelligent information technology, the complexity of a system that is increasingly applicable, makes information technology present and accepted by the public, such as mobile smartphones (mobile computing) with increasingly sophisticated product manufacturing, based on Internet of Things (IoT) technology, and cloud computing suitable for various purposes, such as surveillance, intruder control, and fire detection (Liao et al., 2019; N. He et al., 2017; Srinivasagan et al., 2023.

One of the skills and soft skills needed is the ability to design and implement microcontroller-based systems(Sabri Annas & Gunawan Zain, 2019). Microcontrollers are integrated electronic devices that can be programmed to perform various tasks and have the ability to process data, memory, input/output, and are used to control various devices, ranging from simple electronic equipment such as the ATmega32 microcontroller-based automatic school bell ringing program, to complex industrial machines such as the Industrial Internet of Things (IIoT) that collect data from industrial machines and processes at low cost(Ala-Laurinaho et al., 2020). Data collection allows manufacturers to improve manufacturing processes, as well as products by tracking their performance in the field, improving design and operations, and performing maintenance(Goyal et al., 2019; Schrader et al., 2022.

Microcontrollers have an important role in industry, as they are used to build various control systems and automation of Internet of Things (IoT) devices such as sensors, actuators and various applications in smart manufacturing, robotics, automated transportation, industrial, automotive, remote healthcare using artificial intelligence, and entertainment(Wagan et al., 2022; Kalapothas et al., 2023. Microcontroller learning has experienced rapid development in recent years. This is characterized by the increasing use of microcontrollers as learning objects, with the emergence of new technologies correlated as Algorithms, Big Data, Artificial Intelligence (AI), Internet of Things (IoT), Internet of Services (IoS), Industrial Automation, Cyber Security, Cloud Computing, Machine Learning, and Intelligent Robotics that change the way humans live and work to interact with the world around us digitally. Technology instruments usually feature one or more dedicated microcontrollers, while some systems use separate microcontrollers for each subsystem. The inclusion of small microcontroller chips, smart sensors, and actuators to act in the deployment of smart services to end users(Abbas & Ahmad, 2023; Muhoza et al., 2023; Salazar et al., 2022; Piechocki et al., 2022.

Microcontroller learning has become an important part of the educational curriculum in several countries, various challenges are faced such as the increasing complexity of microcontroller learning materials, the rapid development of technology, and the lack of availability of competent teaching staff. To overcome these challenges, changes are needed in the development of microcontroller learning. These changes include the use of more active and interactive learning methods, the application of innovation-based learning development trends, and the utilization of digital technology in learning. Some previous researchers have identified various microcontroller learning problems, that the teaching of microcontroller programming has an applied character and involves the implementation of training projects that allow teachers to realize educational goals by drawing on knowledge from other fields (programming, physics, mathematics, mechatronics, electronics and others), to introduce creativity into the educational process with the context of digitalization. Then it proposes the experience of organizing project-based learning in the field of microcontroller programming, based on the analysis of scientific, methodological and normative documents, educational activities in microcontroller programming are systematized, which determines the need for structuring educational activities in accordance with project activities in the design of technical systems(Nurbekova et al., 2020).

Students have difficulty in understanding the concept of microcontroller programming and lack of teamwork so that the resulting project is not good, then propose learning microcontroller courses using project-based learning (PBL) which expects students to work together in teams because it allows students to share information, overcome doubts without fear of making mistakes, and strengthen prior knowledge(Camargo L. et al., 2023). Identifying sustainability perspectives from science and engineering fields of study that have not found space in current course curricula, as well as in the mindset of the new generation of engineering undergraduates. The smart greenhouse project is an example of how sustainability can be brought into the classrooms of engineering and technology programs as a project-based learning (PBL) experience, and has the goal of this smart greenhouse project is to create an automated system capable of growing vegetation with little human input by utilizing electricity, computer programming, and microcontroller operation(Kaske Jr et al., 2022).

The limited application of SVM (Space Vector Modulation) based studies in the Power Electronics Laboratory (PEL) due to the vital risks associated with high voltage applications, and not easily learned through mathematical analysis and visual learning without application by students, thus using the simulation and experimental setup of SVM controlled three-phase bi-level inverter and presented in this study by students to learn the basics in PEL(Saribulut & Ameen, 2023).

University 4.0 is needed to prepare students for the Fourth Industrial Revolution, by applying an integrated digital learning model consisting of three areas: communication and creativity, critical thinking and problem solving, and responsibility, and robotics is involved in this approach. Therefore Estevao Ananias and Pedro Dinis Gaspar, developed a low-cost collaborative robot arm using an ESP32 microcontroller, with 6 degrees of freedom to be applied to laboratory teaching and learning activities within the scope of the curricular unit of engineering courses. In addition, it can be used to support research activities within the scope of the project, and even to test its suitability for other types of applications in industry or services outside the educational context(Ananias & Gaspar, 2022).

Many researchers have identified various problems and have carried out solutions related to the learning process using microcontrollers, although the names of the courses taught in the study programs at each university are different. This research aims to map the problems of microcontroller learning and solutions that have been carried out by previous researchers, then summarize and analyze them so that it can be seen what the core problems are related to microcontroller learning in this Industrial 4.0 era. The results of this study can be used as a reference for future researchers, related to microcontroller learning in making more innovative solutions according to the needs of the institution. In addition, the results of this study can also be used as a reference for educational practitioners in determining teaching materials or courses and changes in the education curriculum, where the learning process uses microcontrollers.

2. Case and Methodology

2.1. Research Question

This research uses Systematic Literature Review (SLR) or Systematic Review is a secondary study method that is systematically designed to identify, evaluate, and interpret all available article evidence relevant to the Research Question (RQ) that has been set(Kitchenham & Charter, 2007).

RQ1: What are the problems related to microcontroller learning in the Industry 4.0 era?

RQ2: What are the most popular learning methods related to the learning process using microcontrollers in the Industrial 4.0 era?

2.2. Identification of Studies

The systematic review in this study synthesizes articles using the Watase UAKE application (watase.web.id) which identifies from web pages that are directly connected to Scopus (scopus.com), by going through a systematic literature review search using Prisma (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The Watase UAKE application is an online system designed to conduct research collaboration between researchers. It was pioneered in 2018 by Lilik Wahyudi and friends, and began to be developed by involving researchers from several universities in 2020. Some of the features developed by Watase include: systematic literature review with Prisma, Meta analysis, article classification, and data visualization. Currently Watase has 4,137 users, 73,661 text databases, 153,887 article meta databases, 175,241 database questionnaires.

The initial stage of the process is to determine the research topic, namely Microcontroller Learning Development in Industry 4.0. Next, identify the literature review systematically with Prisma, to obtain research articles from the Scopus database using keyword variables: “development of microcontroller learning in industrial revolution 4.0” OR “development of microcontroller education in industry 4.0” OR “development of microcontroller courses” OR “development of microcontroller studying” OR “microcontroller development with project based learning” OR “microcontroller development with simulation based learning” OR “microcontroller development with cloud based learning” OR “microcontroller development with artificial intelligence based learning”.

The source of this research article was carried out by identifying previous research articles published from 2019 to 2023, articles were selected from quartile levels Q1, Q2, Q3, up to Q4. The mapping of articles based on keywords from Prisma identification can be seen in Fig.1 below:

Figure 1. Article Mapping Based on Keywords

development of microcontroller learning in industrial revolution 4.0

development of microcontroller education in industry 4.0

development of microcontroller courses

development of microcontroller studying

microcontroller development with project based learning

microcontroller development with simulation based learning

microcontroller development with cloud based learning

microcontroller development with artificial intelligence based learning

The results of Prisma identification by reading the title, abstract, and keywords of articles on Scopus.com were obtained as many as 173 articles, as shown in table 1:

Table 1. Identifikasi Prisma

No.	Keyword	Row
1.	development of microcontroller learning in industrial revolution 4.0	3
2.	development of microcontroller education in industry 4.0	5
3.	development of microcontroller courses	73
4.	development of microcontroller studying	25
5.	microcontroller development with project based learning	25
6.	microcontroller development with simulation based learning	6
7.	microcontroller development with cloud based learning	16
8.	microcontroller development with artificial intelligence based learning	20

2.3. Screened

After identifying the prism, the first stage of screening is carried out, namely:

1. Records were deleted before screening, duplicate records were deleted (n = 29)
2. Record flagged as ineligible by automation tool [Year 2019 - 2023] (n = 53)
3. Records deleted for other reasons [Level Q1, Q2, Q3, Q4] (n = 13)
4. Record without abstract for screening (n = 0).

The screening results obtained as many as 78 articles (records screened).

Furthermore, the second stage of screening is to synthesize the appropriate, by reading the abstract, title, and keywords directly, and information in the form of the year the article was published, the number of citations, and the quartile value. From the results of the second stage screening, 42 articles (records excluded) and 36 articles (records included) were obtained, the results of which are shown in table 2.

Table 2. Identifikasi Prisma

PRISMA 2020 – Record Excluded						PRISMA 2020 – Record Included					
No.	Title	Year	Citation	Quartile	Include Yes/No	No.	Title	Year	Citation	Quartile	Include Yes/No
1	(Jamieson et al., 2023)	2023	0	Q2	No	1	(Abbas & Ahmad, 2023)	2023	0	Q3	Yes
2	(Kalapothas et al., 2023)	2023	5	Q2	No	2	(Muhoza et al., 2023)	2023	0	Q1	Yes
3	(Myers et al., 2023)	2023	0	Q2	No	3	(Camargo L. et al., 2023)	2023	0	Q3	Yes
4	(Riskiawan et al., 2023)	2023	0	Q1	No	4	(Saribulut & Ameen, 2023)	2023	1	Q2	Yes
5	(Lall & Tallur, 2023)	2023	3	Q1	No	5	(Srinivasagan et al., 2023)	2023	2	Q1	Yes
6	(Afridi et al., 2023)	2023	0	Q1	No	6	(Hou et al., 2023)	2023	2	Q1	Yes
7	(Y. Xu et al., 2023)	2023	1	Q2	No	7	(Govender & Govender, 2023)	2023	0	Q2	Yes
8	(Morishita et al., 2023)	2023	0	Q3	No	8	(Ananias & Gaspar, 2022)	2022	4	Q2	Yes
9	(Lahme et al., 2023)	2023	0	Q1	No	9	(Kaske Jr et al., 2022)	2022	0	Q4	Yes
10	(T. Wang et al., 2023)	2023	5	Q1	No	10	(Lamo et al., 2022)	2022	1	Q2	Yes
11	(X. Wang et al., 2023)	2023	0	Q4	No	11	(Salazar et al., 2022)	2022	2	Q1	Yes
12	(Acharyya et al., 2023)	2023	1	Q1	No	12	(Idehen et al., 2022)	2022	1	Q1	Yes
13	(Z. He et al., 2023)	2023	0	Q2	No	13	(Dsouza et al., 2022)	2022	0	Q1	Yes
14	(Jia et al., 2024)	2023	0	Q1	No	14	(Piechocki et al., 2022)	2022	1	Q1	Yes
15	(Dhwaj et al., 2022)	2022	3	Q1	No	15	(Tan-a-ram et al., 2022)	2022	0	Q1	Yes
16	(Hasan et al., 2022)	2022	2	Q1	No	16	(Beccaro et al., 2022)	2022	1	Q3	Yes
17	(Futo et al., 2022)	2022	3	Q1	No	17	(Aguilar et al., 2022)	2022	1	Q2	Yes
18	(Schrader et al., 2022)	2022	12	Q2	No	18	(Alajlan & Ibrahim, 2022)	2022	18	Q2	Yes
19	(Marciniak, 2022)	2022	1	Q4	No	19	(Ruo Roch & Martina, 2022)	2022	3	Q1	Yes
20	(Tsai et al., 2022)	2022	8	Q1	No	20	(Velichko, 2021)	2021	7	Q1	Yes
21	(Kalapothas et	2022	8	Q2	No	21	(X. Xu, 2021)	2021	4	Q2	Yes

	al., 2022)										
22	(Yauri et al., 2022)	2022	5	Q3	No	22	(Hernandez-Mangas & Alvarez, 2021)	2021	6	Q2	Yes
23	(Busaeed et al., 2022)	2022	5	Q1	No	23	(Zhou et al., 2020)	2020	13	Q1	Yes
24	(Coelho et al., 2021)	2021	24	Q1	No	24	(Sergeyeva et al., 2020)	2020	2	Q2	Yes
25	(Ravaglia et al., 2021)	2021	25	Q1	No	25	(Merenda et al., 2020)	2020	202	Q1	Yes
26	(Kayan et al., 2021)	2021	12	Q1	No	26	(Moreno et al., 2020)	2020	0	Q2	Yes
27	(FSC Soares, RECR Rodrigues, CM Bossu, MS Soares, SX Santos, GO Uebe, 2021)	2021	0	Q3	No	27	(Kučera, Haffner, Drahoš, Cigánek, et al., 2020)	2020	6	Q2	Yes
28	(Yang, 2021)	2021	5	Q2	No	28	(Barylo et al., 2020)	2020	2	Q4	Yes
29	(Jabavathi et al., 2021)	2021	0	Q3	No	29	(Kučera, Haffner, Drahoš, Leskovský, et al., 2020)	2020	4	Q2	Yes
30	(Dunets et al., 2021)	2021	1	Q2	No	30	(Nurbekova et al., 2020)	2020	10	Q1	Yes
31	(Kuru, 2021)	2021	34	Q1	No	31	(Jawaid et al., 2020)	2020	20	Q1	Yes
32	(Anyanwu et al., 2021)	2021	0	Q2	No	32	(Owen et al., 2020)	2020	4	Q2	Yes
33	(Png et al., 2021)	2021	3	Q2	No	33	(Evsutin & Meshcheryakov, 2020)	2020	13	Q1	Yes
34	(Farooq et al., 2020)	2020	17	Q2	No	34	(Oh, 2019)	2019	3	Q1	Yes
35	(Pipattanasuk & Songsriwittaya, 2020)	2020	11	Q2	No	35	(Lazaro et al., 2019)	2019	38	Q1	Yes
36	(Williams et al., 2020)	2020	2	Q2	No	36	(Damcı & Şekerci, 2019)	2019	13	Q2	Yes
37	(Sanchez-Iborra & Skarmeta, 2020)	2020	152	Q1	No						
38	(Sivaprakash & Venkatesan, 2019)	2019	4	Q2	No						
39	(Di Tore & Raiola, 2019)	2019	3	Q3	No						
40	(Khomutov S. O.Polishchuk V. I.Stashko V. I., 2019)	2019	2	Q2	No						
41	(Martillano et	2019	0	Q3	No						

	al., 2019)				
42	(Sun & Okada, 2019)	2019	3	Q3	No

2.4. Screened

Furthermore, article retrieval is carried out by downloading files from 36 articles, 2 links are available to download:

Url Link 1: doi.org

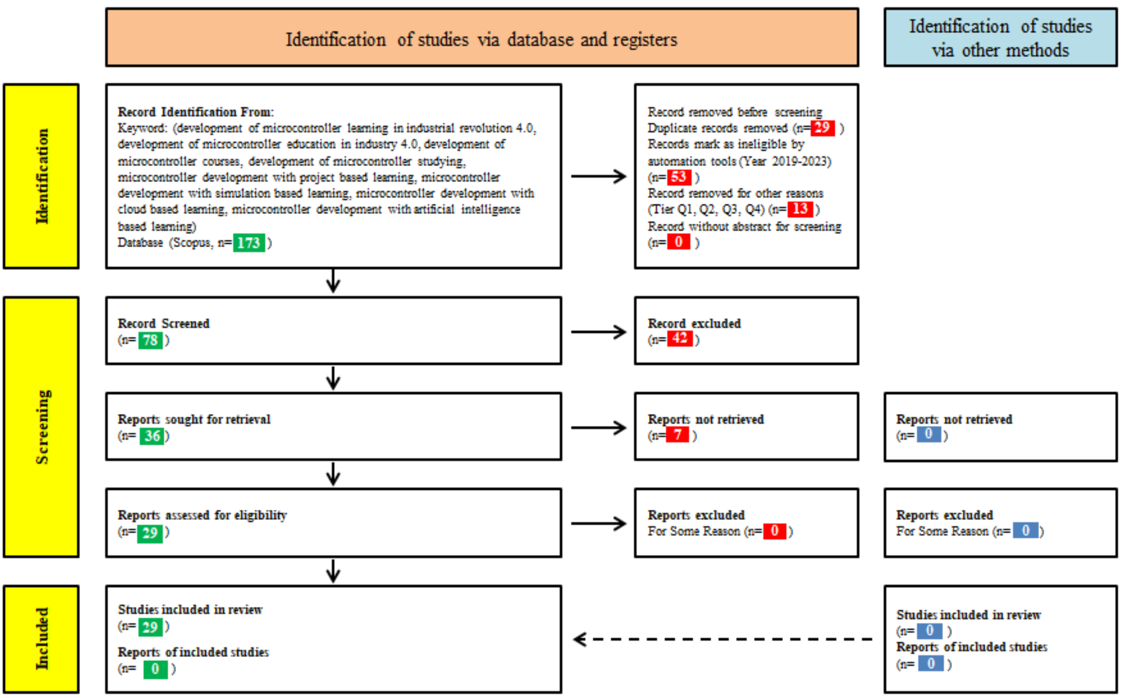
Url Link 2: sci-hub.se

Then obtained 29 pdf file articles that have DOI, and 7 articles that cannot be downloaded. Then the 29 articles that have been downloaded are uploaded into the Watase database and synchronized.

2.5. Report

The process that has been completed by Prisma in the form of identification, screened, and retrieval, provides a report in the form of a flow chart as shown in Figure 2 below:

Figure 2. Results of the Watase Uake Tool, based on the 2020 Prisma Report



Generate From Watase Uake Tools, based on Prisma 2020 Reporting

Based on the results of the Prisma report, it is known that 29 articles have gone through the identification of studies via databases and registers, and more articles can be added if they are deemed insufficient. However, to avoid bias in the reference search, the researchers did not add more articles.

3. Result

3.1. Answering Research Questions Using Meta-Analysis

Meta-analysis is an epidemiologic study design that aims to systematically review, and combine quantitative research estimates from a number of previous studies that address the same research problem and can be combined. Primary analysis is the original analysis of data in a research study, while secondary analysis is the re-analysis of data for the purpose of modifying the original research question with better statistical techniques, or answering new questions with old data. Meta-analysis is defined as the statistical analysis of a large collection of individual study analysis results to integrate the findings(Glass, 1976). In this meta-analysis will be conducted to answer the Research Question (RQ) that has been determined previously.

3.2. Data Extraction

Extraction in the meta-analysis process is the process of taking relevant data or information from primary studies that meet the inclusion criteria. The extracted data or information is then used to analyze and conclude the results of the various primary studies. The data extraction process in meta-analysis is usually done using a coding sheet. The coding sheet contains a list of data or information that needs to be extracted from primary studies. The data or information extracted can be numerical data (such as statistical test results), or categorical data (such as study characteristics).

The extracted data were taken from 29 previously obtained articles. The data included study characteristics viz: type of research from each article to determine the hypothesis of the research that has been done, shown in table 3.

Table 3. Data Extraction

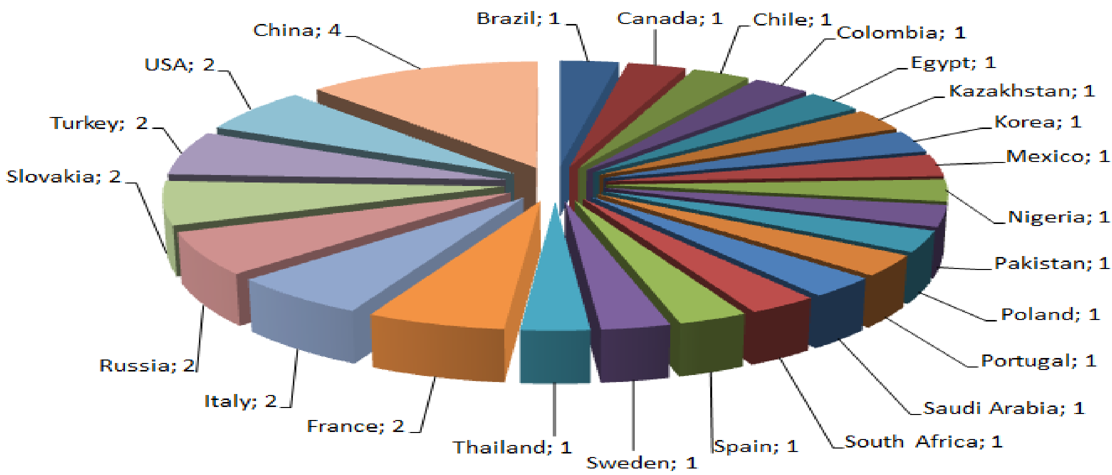
No.	Title	Author's Country	Types of Research			Learning Methods				Learning Object
			Qualitative	Quantitative	Ekspe riment	Project	Simulation	Cloud	Artificial Intelligence	
1	(Jawaid et al., 2020)	Pakistan	Yes	---	Yes	Yes	---	---	---	Robotic
2	(Zhou et al., 2020)	China	---	Yes	Yes	---	Yes	---	---	Virtual Robot Experimentation Platform (V-REP)
3	(X. Xu, 2021)	China	Yes	---	---	Yes	---	---	---	Data Base Management System (DBMS)
4	(Owen et al., 2020)	USA	Yes	---	---	Yes	---	---	---	microcontroller-based TCD (thermal conductivity detectors)
5	(Hernandez-Mangas & Alvarez, 2021)	Spain	Yes	---	---	Yes	---	---	---	the Sinclair ZX Spectrum
6	(Beccaro et	Brazil	---	Yes	Yes	Yes	---	---	---	the STM32F4

	al., 2022)										Microcontroller and uses the Least Mean Square (LMS) algorithm
7	(Govender & Govender, 2023)	South Africa	---	Yes	Yes	Yes	---	---	---		Robotic
8	(Evsutin & Meshcheryakov, 2020)	Russia	Yes	---	---	Yes	---	---	---		The Technology of Blockchain and Digital Watermarking
9	(Oh, 2019)	Korea	Yes	---	Yes	Yes	---	---	---		Internet of Things
10	(Kučera, Haffner, Drahoš, Cigánek, et al., 2020)	Slovakia	Yes	---	Yes	Yes	---	---	---		PN2ARDUINO Based on Petri Nets
11	(Kučera, Haffner, Drahoš, Leskovský, et al., 2020)	Slovakia	Yes	---	Yes	Yes	---	---	---		PetriNet editor + PetriNet engine
12	(Damcı & Şekerci, 2019)	Turkey	Yes	---	Yes	---	Yes	---	---		a low-cost shake table named SARSAR
13	(Tan-a-ram et al., 2022)	Thailand	Yes	---	Yes	Yes	---	---	---		KidBright Board
14	(Nurbekova et al., 2020)	Kazakhstan	Yes	---	---	Yes	---	---	---		Programming Microcontrollers
15	(Muhoza et al., 2023)	France	---	Yes	Yes	---	---	---	Yes		ARM Cortex-M4-based IoT device
16	(Piechocki et al., 2022)	Poland	---	Yes	Yes	---	---	Yes	---		Thermal Image
17	(Alajlan & Ibrahim, 2022)	Saudi Arabia & Egypt	---	Yes	Yes	---	---	Yes	---		TinyML (Deep Learning)
18	(Moreno et al., 2020)	Mexico	Yes	---	Yes	---	---	Yes	---		Internet of Things
19	(Merenda et al., 2020)	Italy	Yes	---	Yes	---	---	Yes	---		Edge ML
20	(Velichko, 2021)	Russia	---	Yes	Yes	---	---	---	Yes		LogNNet System
21	(Idehen et al., 2022)	China & Nigeria	---	Yes	Yes	---	---	Yes	---		Seismograph using Raspberry Pi
22	(Saribulut & Ameen, 2023)	Turkey & Sweden	Yes	---	Yes	Yes	Yes	---	---		Space Vector Modulation (SVM)

23	(Ruo Roch & Martina, 2022)	Italy	Yes	---	Yes	---	Yes	---	---	Technique platform VirtLAB
24	(Camargo L. et al., 2023)	Colombia	---	Yes	---	Yes	---	---	---	microcontroller
25	(Kaske Jr et al., 2022)	USA	Yes	---	---	Yes	---	---	---	Smart Greenhouse
26	(Hou et al., 2023)	France & China	Yes	---	---	---	---	Yes	---	IoT Cloud
27	(Ananias & Gaspar, 2022)	Portugal	---	Yes	Yes	Yes	---	---	---	Robotic
28	(Dsouza et al., 2022)	Canada	---	Yes	Yes	Yes	---	---	---	Respirometric System
29	(Aguilar et al., 2022)	Chile	Yes	---	Yes	Yes	---	---	---	The Plecs RT Box

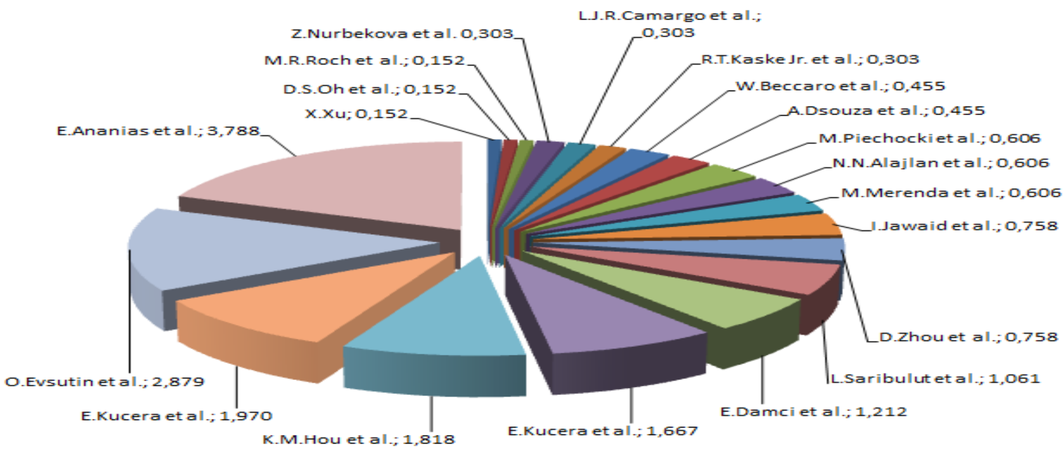
The results obtained after extracting are microcontroller learning following the demands of learning developments in the Industry 4.0 era that have been studied in many countries as shown in figure 3 below:

Figure 3. Authors from Different Countries



Seen in the figure represented by 24 countries, through research on microcontroller learning and its development in following the demands of industrial development trends in the Industry 4.0 era. Then based on the results of data extraction, reading the contents of the article carefully and using Mendeley Desktop which talks about Industry or Industry 4.0 or Industrial Revolution 4.0 there are 20 articles, with the results of the percentage value as shown in figure 4. Researchers clearly, and continuously talk about the industry in their articles.

Figure 4. Authors who actually talk about the Industry

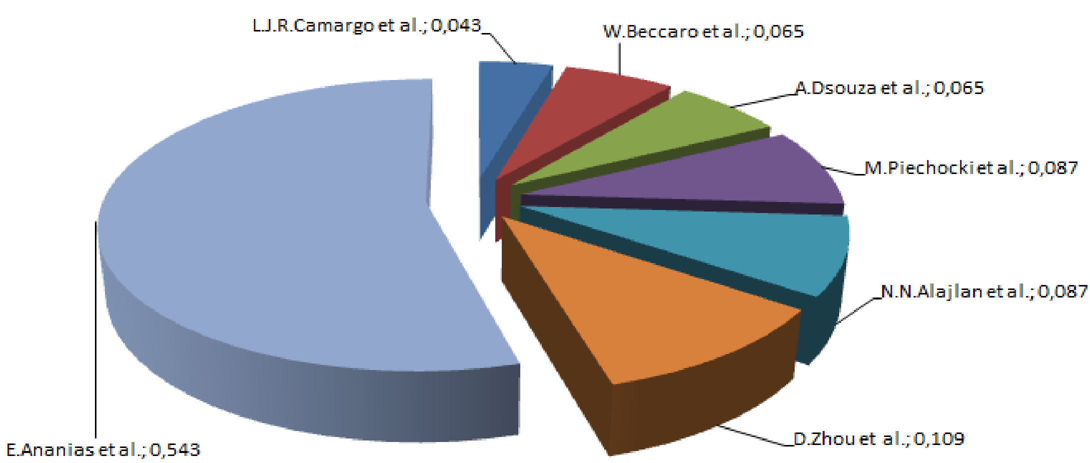


Furthermore, the 20 articles are divided into 2 groups of research types, namely qualitative research and quantitative research, as shown in table 3 above. The extraction results obtained 13 articles that are qualitative research and 7 quantitative research articles. While those that will proceed to the classification process are only quantitative articles, because quantitative research conducts experiments by collecting data using measuring instruments or research instruments, and the process of analyzing data in the form of numbers carried out is graphical or statistical.

3.3. Classification Process

There are 7 articles that are articles with quantitative research types that will be classified, as shown in Figure 6. The classification process by reading the contents of the article carefully and using the help of Mendeley Desktop, researchers who talk about the subject matter and solutions in solving existing problems.

Figure 5. Articles with Quantitative Research Results



The problem is that many production systems in Industry 4.0 require collaboration between robotics and humans that can work safely side by side. The solution is to present the development and testing of a standardized, low-cost 6-axis collaborative robot that can be used for educational purposes in a variety of specialized task applications. So to face this challenge, a new generation of robots called cobots or "Collaborative Robots" was developed. The research conducted considers the development of user interface applications with the robot arm, the application of technological solutions, as well as the scientific and educational approaches used in the development of Collaborative Robots that can drive the widespread implementation of Industry 4.0(Ananias & Gaspar, 2022).

The problem in teaching students is the difficulty in applying the principles of pure mathematical algorithms in robotics to the development of real robots in traditional classrooms. The solution is to provide a new robotics teaching method, namely the development steps of the complete robot algorithm, virtual experimentation, programming and controller (AVPC), and teach the kinematics of the 6-DOF desktop robot arm, using the inverse kinematics algorithm realized in MATLAB, and the dynamic model of the desktop robot arm established in the Virtual Robot Experimentation Platform (V-REP). This new teaching method has a significant impact on improving students' learning effect on robotics learning(Zhou et al., 2020).

Menghubungkan perangkat IoT ke cloud untuk mentransfer data mentah dan melakukan pemrosesan menyebabkan respons sistem tertunda, mengekspos data pribadi, dan meningkatkan biaya komunikasi. Solusi yang dilakukan adalah dengan adanya teknologi baru yang disebut Tiny Machine Learning (TinyML), yang telah membuka jalan untuk memenuhi tantangan perangkat IoT. Penelitian ini menggambarkan secara umum tentang revolusi TinyML dan tinjauan studi tinyML, di mana kontribusi utamanya adalah untuk memberikan analisis tentang jenis model ML yang digunakan dalam studi tinyML, dan menyajikan rincian dataset dan jenis dan karakteristik perangkat dengan tujuan untuk memperjelas keadaan dan membayangkan persyaratan pengembangan. Teknologi ini memungkinkan pemrosesan data secara lokal di perangkat tanpa perlu mengirimnya ke cloud(Alajlan & Ibrahim, 2022).

Non-optimal strategies exist and lead to large amounts of wasted energy due to inadequate system control on the use of simple binary presence detectors used to control the operation of HVAC systems in most rooms, halls, and auditoriums. The solution is to describe a method for efficient occupancy estimation based on low-resolution thermal images. The approach utilizes a U-Net-like convolutional neural network capable of estimating the number of people in the sensor's field of view. Although the architecture was optimized and quantized to fit the limited microcontroller memory, the metrics obtained by the algorithm outperformed other state-of-the-art solutions. Tests were then conducted on embedded processors enabling comparison of various chips and proving that people counting can be efficiently executed on hardware with limited resources while maintaining low power usage(Piechocki et al., 2022).

Respirometry systems and CO2 sampling methods can be expensive, operationally complex, and produce data that has low temporal resolution. Yet aerobic respirometry, which involves measuring the carbon dioxide (CO2) that evolves during decomposition, is an invaluable metric for evaluating biomass decomposability, characterizing compost feedstocks, and studying decomposition dynamics over time. The solution undertaken was to detail the technical development and validation of an automated multi-ship respirometry system using off-the-shelf microcontrollers and miniaturized non-dispersive infrared (NDIR) CO2 sensors to generate high-resolution and temporally accurate CO2 data generated from decomposing biomass. The accuracy of the NDIR CO2 sensor, as given by cumulative CO2 (g), was validated through an acetic acid-sodium bicarbonate reaction test. In this test, an average cumulative CO2 evolution of 0.99 g (n=8) was measured with the sensor from an expected stoichiometric yield of 1 g CO2, with a standard deviation of ±0.137 g. The operation, reliability, and reproducibility of the system were tested through a series of biomass decomposition experiments(Dsouza et al., 2022).

Didactic platforms used as digital signal processors or field-programmable gate arrays are costly and difficult to program. The solution is to use new technologies of digital signal controllers, microcontrollers with floating point and mathematical operations, can reduce the cost of dedicated platforms for real-time digital signal processors, facilitate the development of digital signal processor projects and educational applications, such as teaching adaptive filters. Using a low-cost didactic platform to develop real-time adaptive filters with digital signal processor hardware based on the ARM Cortex-M7 processor. Presents theoretical aspects of the least mean square and normalized least mean square algorithms and experimental scripts to help students learn real-time adaptive filters. As well as describing the platform structure and performance measurements, in terms of mean square error, signal-to-noise ratio, and computational efficiency. Finally, we present a brief discussion on the use of this platform in the classroom and the increase in student engagement and attendance(Beccaro et al., 2022).

Project-based learning (PBL) as a didactic tool to fulfill learning outcomes (LRs), increasing students' motivation and willingness to learn in the Digital Design course using Microcontrollers. Students are given all the information related to the project, the design methodology, everything needed in the project, and how to evaluate the results of the project. Then comparing the quantitative results obtained from the course in the previous semester with those obtained after applying the project-based learning methodology, a significant improvement can be seen viz: the percentage of students who passed is significantly higher(Camargo L. et al., 2023).

4. Discussion

The classification process produces a hypothesized correlation between the problem value and the solution value in percentage, there is a relationship between the problem and solution in this study, as shown in table 4 and table 5. The percentage value of the problem is obtained from:

$$P_n = \frac{P}{P+S} \; x \; 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Pn is the percentage value of the problem

P is the problem value of each article

S is the solution value of each article

The results of the calculation of the percentage value of the problem can be seen in table 4 below:

Table 4. Problem Percentage Hypothesis

Code	Author	Object Problem	P	S	Percentage
P1	(Ananias & Gaspar, 2022)	Robotic	10	4	0,714
P2	(Zhou et al., 2020)	Robotic	79	87	0,476
P3	(Alajlan & Ibrahim, 2022)	IoT Edge devices to Cloud	8	8	0,500
P4	(Piechocki et al., 2022)	Control system detector is not maximized	5	1	0,833
P5	(Dsouza et al., 2022)	Sensor Sistem Respirometri CO2	21	7	0,750
P6	(Beccaro et al., 2022)	Digital signal processor or gate array	11	8	0,579
P7	(Camargo L. et al., 2023)	Microcontroller learning methods	23	8	0,742

The percentage value of the solution is obtained from:

$$S_n = \frac{S}{P+S} \ x \ 100\% \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Sn is the percentage value of the solution

S is the solution value of each article

P is the problem value of each article

While the results of the calculation of the percentage value of the solution can be seen in the following table 5:

Table 5. Solution Percentage Hypothesis

Code	Author	Object Problem	P	S	Percentage
S1	(Ananias & Gaspar, 2022)	“Cobot” Robot Colaborative	4	10	0,286
S2	(Zhou et al., 2020)	Robot Kinematics	87	79	0,524
S3	(Alajlan & Ibrahim, 2022)	Tiny Machine Learning (TinyML)	8	8	0,500
S4	(Piechocki et al., 2022)	U-Net like convolutional neural network	1	5	0,167
S5	(Dsouza et al., 2022)	Miniature Non-Dispersive Infra Red (NDIR) CO2 sensor	7	21	0,250
S6	(Beccaro et al., 2022)	Digital signal processor or gate array using ARM Cortex-M7 processor	8	11	0,421
S7	(Camargo L. et al., 2023)	Project Based Learning (PBL)	8	23	0,258

P1 research conducted by Estevao Ananias et al. conducted research with the object of the problem regarding Robotic with the results of the hypothesized problem value of 0.714 and solved the problem solution with the object of the solution using "Cobot" or Collaborative Robot in a scientific and educational approach with the results of the hypothesized solution value S1 is 0.286.

Meanwhile, P2 research conducted by Dongxu Zhou et al. conducted research with the object of the problem regarding Robotic with almost the same problem as P1, with the hypothesized value of the problem 0.476 and solved the solution of the problem with the object of the solution using MATLAB-based Kinematic Robot and V-REP on the teaching method of theory and application with the hypothesized value of S2 solution is 0.524.

P3 research conducted by Norah N. Alajlan et al. conducted research with the object of the problem regarding IoT Edge devices to the Cloud with the hypothesized value of the problem 0.500 and solved the problem solution with the object of the solution using Tiny Machine Learning (TinyML) in activating the Deep Learning learning model on ultra-low power IoT Edge devices for AI applications with the hypothesized value of S3 solution is 0.500.

P4 research conducted by Mateusz Piechocki et al. conducted research with the object of the problem regarding the control system detector that works not optimally, with the hypothesis result of the problem value of 0.833 and solved the problem solution with the object of the solution using U-Net such as convolutional neural networks in viewing Thermal Images with the hypothesis result of the solution value S4 is 0.167.

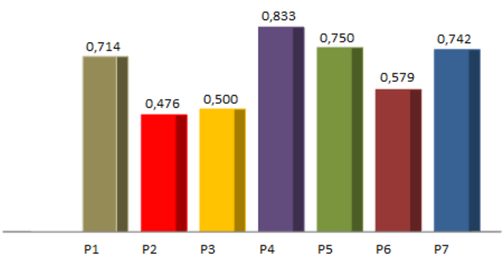
P5 research conducted by Ajwal Dsouza et al. conducted research with the object of the problem regarding the CO2 respirometry system sensor with the hypothesized result of the problem value of 0.750 and solved the problem solution with the object of the solution using the Miniature Non-Dispersive Infra Red (NDIR) CO2 sensor to evaluate the decomposition of composting raw materials with the hypothesized result of the S5 solution value of 0.250.

P6 research conducted by Wesley Beccaro et al. conducted research with the object of the problem regarding the signal processor or gate array with the hypothesized value of the problem 0.579 and solved the problem solution with the object of the solution using Digital signal processor or gate array using ARM Cortex-M7 low-cost processor with the hypothesized value of the solution S6 is 0.421.

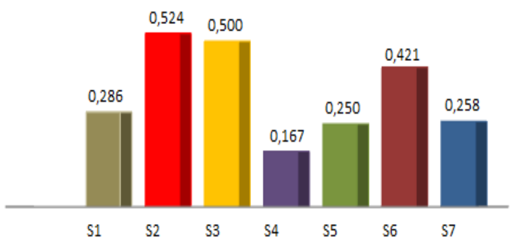
P7 research conducted by L. Julian R. Camargo et al. conducted research with the object of the problem regarding Microcontroller learning methods with the hypothesized value of the problem 0.742 and solved the problem solution with the object of the solution using Project Based Learning (PBL) based learning in microcontroller lessons with the hypothesized value of the solution S7 is 0.258.

Figure 6 shows a comparison chart between the discussion of problems and discussion of solutions from 7 quantitative research articles that have been selected until the classification process in the meta analysis.

Figure 6. Problem and Solution Percentage



Probleme Percentage



Solution Percentage

In the graph, it can be seen that the comparison of Dongxu Zhou et al's research results provides more and more detailed explanations in the description of the solution of their research results, compared to the description of the existing problem explanation. This is possible so that readers and users of the article can clearly understand the results of their research and obtain useful information from the experimental results conducted by Dongxu Zhou et al.

While the research conducted by Norah N. Alajlan et al. provides an equal amount of explanation between the description of the solution of the research results and the description of the explanation of the problem at hand. While the other five articles provide more explanation on the description of the problem at hand, compared to describing the solution and explaining the quantitative results that have been obtained.

5. Conclusion

After going through the Systematic Literature Review (SLR) or Systematic Review process and continued with the Meta Analysis process, the results were obtained to find problems related to microcontroller learning in the Industry 4.0 era. The problems are grouped into 3 parts based on the learning methods used, namely:

1) Project Based Learning (PBL) there are 4 problems consisting of robotic, CO2 respirometry system sensor, signal processor or gate array, and microcontroller learning methods.

2) Simulation Based Learning (SBL) there is 1 problem, namely robotic

3) Cloud Based Learning (CBL) there are 2 problems consisting of IoT Edge devices to the Cloud, and control system detectors.

Then from these problems, the right solution is obtained in the world of education to face the development of the current industrial revolution. The solution is divided into 3 parts based on the learning methods currently used in education, namely:

1) Project Based Learning (PBL) there are 4 solutions consisting of "Cobot" or Collaborative Robot, Miniature Non-Dispersive Infra Red (NDIR) CO2 sensor, Digital signal processor or gate array using ARM Cortex-M7 processor, and Project Based Learning (PBL) based learning.

2) Simulation Based Learning (SBL) has 1 solution, namely MATLAB-based Kinematic Robot and V-REP.

3) Cloud Based Learning (CBL) there are 2 solutions consisting of Tiny Machine Learning (TinyML) in enabling Deep Learning learning models on IoT Edge devices, and U-Net such as convolutional neural networks in viewing Thermal Images.

The most popular learning method related to the learning process using microcontrollers in the Industry 4.0 era is the Project Based Learning (PBL) learning method because this learning method provides material focused on solving real problems, namely making certain useful tools. This method can provide meaningful learning experiences for students and prepare them to face challenges in the world of work. Project Based Learning (PBL) can provide benefits for learners, including: improving problem solving skills, increasing creativity and innovation, improving critical thinking and analysis skills, and improving the ability to collaborate in teams.

Further research is expected to make a real contribution in the face of increasingly advanced and rapid industrial development, especially in the use of microcontrollers in education.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

Krismadinata conducted the research and verified the manuscript before submission. Sigit Candra Setya conducted the research and wrote the manuscript. Ganefri improved the writing and language quality of the manuscript before submission, and contributed some ideas to the manuscript. Jusmita Weriza collected and managed the empirical data and verified the manuscript before submission. All authors have approved the final version.

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