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Designing serious simulation game mechanics for learning karakuri-based low-cost automation

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ABSTRACT

Automation in industrial development is one of the requirements for a manufacturer to increase productivity. This is often accompanied by a big cost with modern machinery. Karakuri offers a low-cost approach by using simple mechanical arrangements and basic physical principles to perform tasks without complex machinery. This study aims to design the mechanics of a serious simulation game for learning Karakuri concepts and exploring their application to material handling automation. The design combines game mechanics and learning mechanics to connect players' decisions with the intended learning objectives. Players engage with realistic industrial scenarios, explore alternative solutions, and receive immediate feedback on the consequences of their choices. These interactions are intended to help players build mental models of how Karakuri mechanisms work and when they may offer suitable automation solutions. The resulting mechanics provide a foundation for developing a complete simulation game that links conceptual learning with practical problem-solving. The study contributes a learning-oriented game design intended to encourage consideration of Karakuri as an accessible approach to low-cost material handling automation.

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1. Introduction

Automation and robotics, which are recognized as key components of Industry 4.0, are now widely used, and connected to digital technology with mostly need a big cost. This research tries to explain the alternate automation with similar origins of robotics through the example of premodern Japanese automata, or karakuri, with an emphasis on the answers these primitive robots can offer and how humans can benefit from this technology. deliver in the modern setting of Industry 4.0, with the demands of the 21st century in mind.

Most of the human life, which is focused on trade, education, healthcare services, labor, and industry, is influenced by the relationships between people, society, machines, and ever more machine. As a result, the advancement of technology has increased the demand for all types of energy used to operate machinery, digital devices, and robotics. As can be seen in Fig. 1, energy consumption increases significantly with technological advancements discussed here as the number of transistors per microprocessor (the extent of these technological advancements is limited by the assertion that Industry 4.0 solutions are particularly disruptive in today's computerized world) (Hussain & Sia, 2022).

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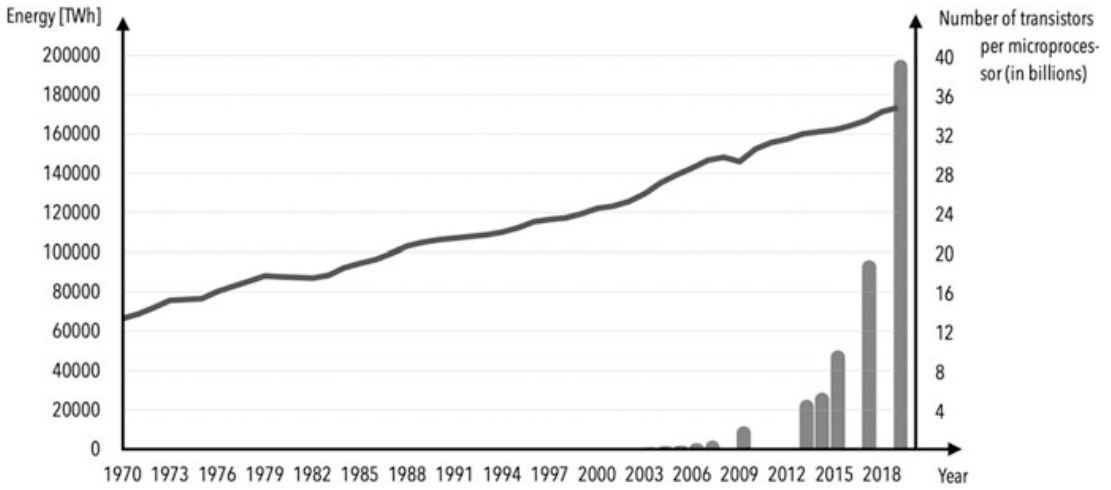

Fig. 1 Comparison of number of transistors per microprocessor and global energy consumption.

The phrase "karakuri kaizen" which refers to continuous improvement using updated karakuri applications, is associated with the current application of karakuri. As can be seen from Fig. 2, this modern application has piqued academics' curiosity, however somewhat. In contrast to Industry 4.0, which is digitalized, karakuri kaizen is analogue automation. However, unlike Industry 4.0, it is not connected to every variety of recently developed technologies, such as Narrow Band Internet of Things (NB-IoT), Global Positioning System (GPS), Wireless Sensor Network (WSN), Near-Field Communication (NFC), Global Positioning System (RFID), Wireless Fidelity (Wi-Fi), Fifth-Generation mobile networks (5G), Global Positioning System (GPS), and robotics (Liu et al., 2018). The Karakuri Kaizen method can serve as a valuable development and implementation phase in material handling for Industry 4.0 by promoting process simplification, automation, flexibility, employee engagement, and cost-effectiveness. It provides a practical and accessible approach to improving material handling processes while laying the groundwork for the adoption of more advanced technologies and concepts associated with the fourth industrial revolution.

It is susceptible to the straightforward physical phenomena and workings of the times before electricity was invented; it is both simple to create and sustain. In many manufacturing subsectors, karakuri kaizen is implemented through the utilization of very complicated mechanical systems that make use of simple phenomena. Gravity, magnetic, friction, force, lever, weight-shift, gears, spring, pulley, roller, water jets, seesaws, counterweights, dampers for energy dissipation, light reflection and refraction, gas or liquid flow, etc. are a few examples of mechanisms used in karakuri implementation (Rani et al., 2015). These mechanisms are all applied to transform the initial input into a different kind of movement. (Besiroglu 2017 recalled them all to the following forces' terms: force of gravity, clamping force, radial force, tensile force, spring force, hydropower).

2. Methods

Research from (Lukosch et al., 2018) develop a framework to design a Serious simulation game in 7 steps. Of the several methods most widely used in developing a serious simulation game, this research uses two methods, namely the Triadic Game Design game design philosophy (Harteveld, 2011) and the game design framework (Lukosch et al., 2018). First, analyzing the elements of the real system. Second, defining the overall aim of the game. Third, deciding which elements of reality underpin the real-world problem as well as the objective of the game. Fourth, defining how these elements should be represented within the game. Fifth, define how the player can use and act upon these elements within the game. Sixth testing and redefining the game design. Seventh, designing a game session from debriefing and additional research tools to provide feedback both to the players as well as the researchers. Triadic Game Design (TGD) is a philosophy of three elements that must be present in a game with serious goals, namely reality, meaning and the nature of play. These three elements are inherently connected and interdependent on each other. There is a balance between

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these three elements and must be balanced in designing the game. If the elements in it are not balanced, then the game's objectives will not be achieved.

Serious simulation games are a learning tool that is free from doubts about failure and can change thinking models (Hidayatno et al., 2018). This can be seen in Fig. 2 which shows that the simulation provides feedback from the real-world model so that it can build a mental model which will ultimately influence the decision-making system.

At the philosophical level of game science, serious simulation games can be used as research tools, to support the analysis and design of complex systems. Serious simulation games are useful in representing dynamic systems and situations, including social or human factors and represent a tool for studying and discussing system complexity and behaviour.

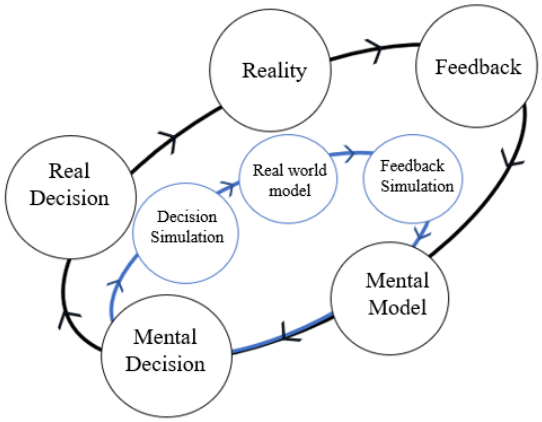

Fig. 2 The role of simulation in the learning cycle (Hidayatno et al., 2018).

3. Results and Discussion

The designed game expects players to reach the creating point which is the fifth level of the Revised Bloom Taxonomy (Anderson et al., 2000) as shown in Fig. 3.

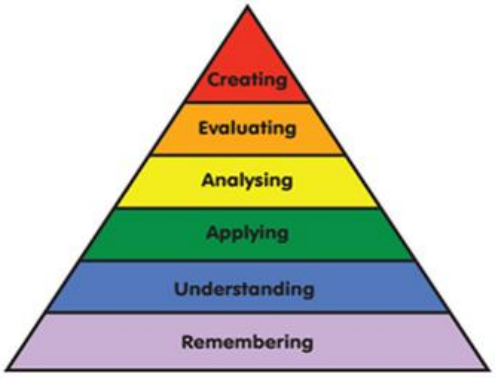

Fig. 3 Revised Bloom taxonomy (Anderson et al., 2000).

This activity starts with how players can understand the condition of abilities during the game and then applying strategies that are thought to improve the situation. After carrying out the strategy the player receives feedback from the strategy and can analyze the difference between the expectations to be achieved and the events that occur. Then, players can evaluate the flow of strategy and feedback so they can predict events and make decisions. Finally, the player can create a new design for further development.

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3.1. Learning - Game Mechanics from the Game

To translate learning outputs into the form of required learning mechanisms, the framework. In simple terms, the LM-GM model has two axes (Arnab et al., 2015). The middle column shows the abilities at the level of thinking according to the revised Bloom taxonomy (Anderson et al., 2000) while on the right side are the learning points at that level of thinking. Meanwhile, on the left side is game mechanics, namely how to translate these learning points in the game.

Table 1 Learning and game mechanics framework

Game Mechanics		Thinking Skills	Learning Mechanics	
Design/Editing Infinite Game play	Status Strategy/Planning	Creating	Accountability Ownership	
Ownership	Tiles/Grids		Planning	
Protégé Effect			Responsibility	
Action Points Assessment Collaboration	Game Turns Pareto optimal Rewards/Penalties		Assessment Collaboration Hypothesis	Motivation
Communal Discovery	Urgent Optimism	Evaluating	Incentive	Reflect/Discuss
Resource Management				
Feedback Meta-game		Analysing	Analyse Identify Experimentation Observations	
Realism			Feedback Shadowing	
Capture/Elimination	Progression		Action/Task	Imitation Simulation
Competition Cooperation	Selecting/Collecting Simulate/Response	Applying	Competition Cooperation	
Movement	Time Pressure		Demonstrating	
Appointment Cascading Information	Role-play Tutorial	Understanding	Objectify Tutorial Participation	
Questions and Answers			Questions & Answers	
Cut scenes/Story Tokens	Behavioural Momentum Pavlovian Interactions	Retention	Discover Guidance	Generalisation Repetition
Virility	Goods/Information's		Explore Instruction	

Source: (Anderson et al., 2000)

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3.2. Karakuri for Kaizen

Kaizen is used in many manufacturing subsectors in the form of mechanical systems that are quite complicated but yet make use of simple occurrences. Gravity force, magnetic force, friction force, lever mechanisms, weight-shift mechanisms, gears, spring mechanisms, pulley mechanisms, roller mechanisms, water jets, seesaws, counterweights, dampers for energy dissipation, light reflection and refraction, gas or liquid flow, etc. are just a few examples of the mechanisms used in karakuri implementation (Rani et al., 2015). All of these force types are applied to change the initial input into a different kind of movement. (Besiroglu, 2017) reminded them all of the terms for the following forces: force of gravity, clamping force, radial force, tensile force, spring force, hydropower. It is not totally accurate to characterize karakuri as energy-free motion as (Arslankaya & Yonar, 2015) did. Karakuri technology, as noted by (Katayama et al., 2019) and (Tortorella et al., 2020), uses elemental physical contrivances in conjunction with natural energy.

3.3. Basic of Karakuri Mechanism

There are some basic mechanisms of Karakuri (Keisuke Saka, 2010) that can be used to apply the Karakuri concept. The way it works is based on physical movement with the basis of applying force at one point which can provide a chain reaction to surrounding objects. Below is the some basic of Karakuri Mechanism:

3.3.1. Lever

Lever is one of the the oldest mechanisms invented by humans. A lever is a simple machine tha tcan multiply and pllied mechanical folce or change the direction of a force. Levers tend to go unnoticed because the mecahism is commonly used in almos every tool and machine.

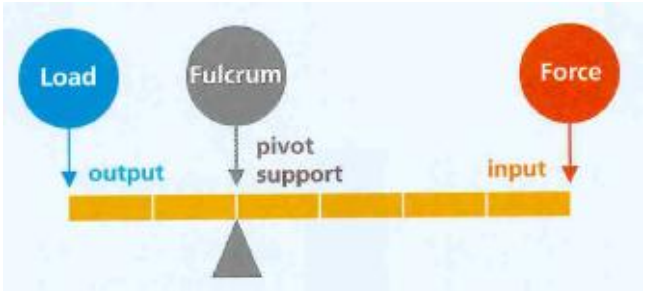

Fig. 4 Example of Lever (Keisuke Saka, 2010).

3.3.2. Cam

A cam is a mechanism that turns or moces variously shaped disks on order to change the direction or rhythm of how parts move along the contour of those disks. It is used in many machines to make intricate movements with fewer parts, just by changing shape ok the disk.

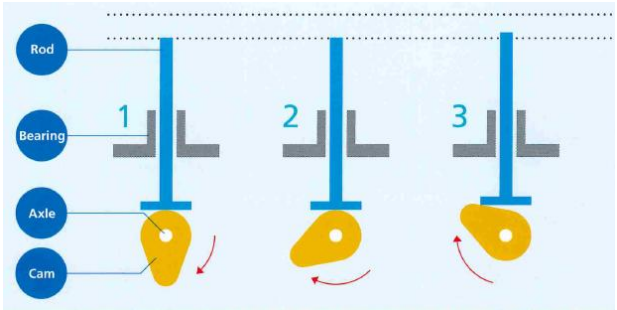

Fig. 5 Example of Cam (Keisuke Saka, 2010).

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3.3.3. *Crank*

A crank is a mechanism that uses a hook-shaped axle to convert a rotation into a liniear motion, or vice versa, a linear motion into a rotation. By combining a crank with a linkage, a very complicated motion can be produced.

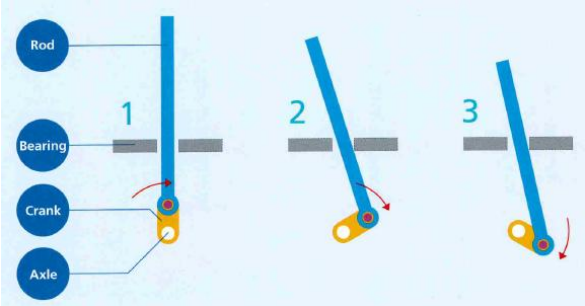

Fig. 6 Example of Crank (Keisuke Saka, 2010).

3.3.4. Gear

A gear is a mechanism used in things such as a watch or bicycle. It can change the direction of rotation, as well as the speed and amount of force. Gears can engage with not only other gears, but also a chain or a belt to exert force over a distance.

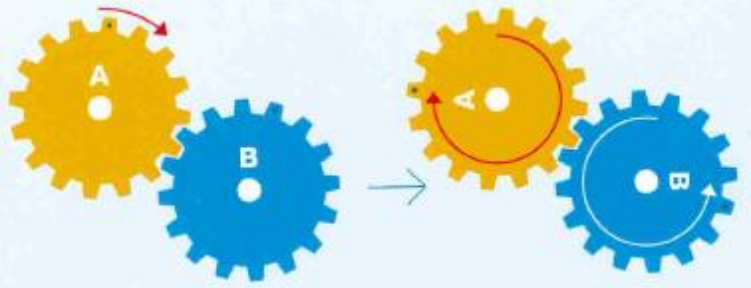

Fig. 7 Example of Gear (Keisuke Saka, 2010).

The four basic movements above can be developed or combined to create movements according to your needs. Basically this can be achieved just by using shaped paper for a small experiment. However, it does not rule out the possibility of being made using stronger materials in accordance with industrial needs.

3.4. Game Mechanic Determination

In determining Game Mechanics (GM), it is necessary to first determine the learning mechanics (LM) of the game. Because players in this game are expected to not only increase their knowledge but are expected to be able to create automation with Kararuki, the expected Taxonomy Bloom level is at level 6, namely creating. So from determining this level, learning targets can be created and game mechanics determined as follows in Table 2.

Table 2 LM – GM of the Game

Actor	Rule and responsibility	Specification	Output	Game Mechanics	Learning Mechanics
Kaizen Team	Production flow	Material Handling	On time goods	Design/Editing Infinte Game play, Status Strategy/Planning, Ownership	Accountability Ownership, Planning, Responsibility

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The actors in this game are the Kaizen Team whose task is to expedite the movement of goods in the production process with the target of arriving the product on time. The game mechanics provided are that players are expected to be able to design the construction of the karakuri system to ensure a smooth process so that they can also learn a sense of responsibility for the results of the designs that have been made.

Next, a translation of LN-GM to Game was made. In accordance with the solution offered to Karakuri, it is low cost and does not require energy from fuel, this is the actor's output target. Of course, the target is that the goods sent will arrive on time at the next production station. Determination of elements is carried out in accordance with learning needs, namely the presence of a production flow board to make it easier for actors to understand the flow and the basic components of the karakuri that has been made so that they can immediately run the simulation and get feedback from the construction changes made.

The results of LM-GM can be used to determine game components and determine how players will interact. This research provides valuable insights and practical applications for industries looking to implement cost-effective and efficient automation solutions based on the principles of Karakuri. By leveraging the Serious Simulation Game mechanic, industry professionals can enhance their skills, optimize production processes, and drive innovation in material handling automation.

Table 3 Translation of LM – GM to the Game

Actor	Decision Variables	The interests/outputs of each actor	Thinking Ability	Game Mechanics	Learning Mechanics	Input in game elements	Translation of game elements	Game mechanic translation
Kaizen Team	Moving goods without a fuel engine	Material handling without fuel	Creating	Design / Editing Infinte Game play, Status Strategy/Planning, Ownership	Accountability Ownership, Planning, Responsibility	Current construction of goods movement	Production flow board and four karakuri components	Simulate the application of karakuri with the available scenarios
	Transport time does not increase	Material handling went smoothly				Items to be moved	Material components	

4. Conclusion

Basically, this research tries to adapt the Karakuri simulation to the context of material movement based on basic Karakuri standards. The learning target of the designed game is at level 6 of Bloom's taxonomy with the context of serious simulation games which are divided into learning mechanics and game mechanics. The players in this game are a kaizen team whose target is to improve material handling by considering Karakuri. This is based on a decision-making variable that avoids the use of fuel but produces material movement times that are no slower than before.

For the future research needs to be carried out to determine additional elements and scenarios from the industrial sector to determine the game flow in accordance with the SSG creation framework so that further game experiment iterations can be carried out.

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