Analysis of Tacit Knowledge Acquisition During Production Line Design Education Using LEGO Bricks

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***Abstract*— In the manufacturing industry, the aging of skilled engineers and the shortage of human resources have made the transfer of experiential knowledge related to production line design a crucially important issue. This study analyzed the process by which students acquire tacit knowledge through production line design and improvement activities and subsequently transform it into explicit knowledge. The analysis, based on a production line design exercise using LEGO bricks conducted with 42 students, involved measuring and comparing assembly times in both the cell production system and line production system, examining production improvement activities, and analyzing the assembly manuals and reflective reports created during the exercise. The results revealed that students recognized production issues such as bottlenecks and line balancing through hands-on experience. Furthermore, through iterative trial-and-error improvement activities, they developed tacit knowledge related to optimization of the four fundamental production factors: Man, Machine, Material, and Method (4M). Findings also confirmed that students converted this tacit knowledge into explicit knowledge by articulating and documenting their findings in the form of work standards, assembly procedures, and improvement proposals.**

These findings suggest that experiential learning promotes the acquisition of practical knowledge and the creation of new knowledge necessary for production line design. Moreover, such educational approaches can serve as an effective means of transferring the experiential expertise of skilled engineers to the next generation.

Keywords— Experiential Learning, LEGO Bricks, Manufacturing Education, Production Line Design Education, Tacit Knowledge

I. INTRODUCTION

The aging of skilled engineers and the shortage of human resources in the manufacturing industry have made the transfer of skills and know-how accumulated through years of experience an increasingly important challenge. The Monodzukuri White Paper [1] also highlights the decline in the number of skilled workers and the growth of the labor shortage in the manufacturing sector. Production line design, which is indispensable to manufacturing operations, necessitates the comprehensive optimization of the four key production factors known as the 4M framework: Man, Machine, Material, and Method. Designers must satisfy the requirements of quality, cost, and delivery (QCD) while also considering safety, flexibility, and maintainability. Consequently, production line designers are expected to possess advanced decision-making capabilities that integrate diverse technical and operational factors. Much of this capability relies on tacit knowledge acquired through practical experience in design and continuous improvement activities.

Regarding knowledge transfer in manufacturing, Brito et al. [2] emphasized the importance of interaction between tacit and explicit knowledge in organizational knowledge transfer. Furthermore, Nonaka and Takeuchi [3] systematized organizational knowledge creation through the SECI model, which comprises four stages: Socialization, Externalization, Combination, and Internalization. The SECI model has been accepted widely as a theoretical framework for explaining how tacit knowledge based on individual experience evolves into organizational knowledge. More recently, Han and Zhao [4] reexamined SECI model applicability in educational contexts and demonstrated empirically that knowledge creation processes promote students' creative behavior. After Dmitrij [5] analyzed knowledge conversion processes in digital learning environments, they reported that the SECI model remains an effective analytical framework in contemporary educational settings. These findings reported from earlier studies suggest that the SECI model is useful not only for elucidating knowledge transfer in manufacturing organizations but also for analyzing knowledge creation processes in educational environments.

Against this background, this study was conducted to analyze how students acquire tacit knowledge related to production line design and transform that tacit knowledge into explicit knowledge through a production line design exercise using LEGO bricks. The analysis specifically examines measurements and reflections related to assembly times in both cell production system and line production system, the content of production improvement activities, and assembly manuals and reflective reports prepared by 42 students. By examining these learning outcomes through the theoretical lens of the SECI model, this study was conducted to clarify the characteristics of knowledge acquisition and knowledge conversion in production line design education. The findings are expected to provide insights into designing educational approaches that support knowledge transfer and human resource development in the manufacturing industry.

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II. Theoretical Framework: Knowledge Creation Based on the SECI Model and Its Application to This Study

This study adopts the SECI model proposed by Nonaka and Takeuchi [3] as its theoretical framework to analyze processes through which students acquire tacit knowledge and transform it into explicit knowledge in production line design. According to the SECI model, knowledge creation advances through the continuous and cyclical interaction of four processes: Socialization, Externalization, Combination, and Internalization. Recent studies have shown that the SECI model has continued to serve as an effective framework for explaining knowledge creation processes [4, 5]. As presented in Figure 1, the learning process students experience in production line design education can be readily mapped onto the four-quadrant SECI model.

1. Socialization (Tacit-Tacit Knowledge Conversion):
   Students engage directly in LEGO brick assembly activities as a form of experiential learning. Moreover, they observe the movements, work methods, and part arrangements of others. Through these experiences, they share and acquire tacit knowledge, including unarticulated work techniques, practical tips, and perceptions of task difficulty.
2. Externalization (Tacit-Explicit Knowledge Conversion):
   Through trial-and-error during experiential learning, students identify inefficiencies such as unnecessary searching for parts and excessive motion. They then articulate their insights and document them in the form of layout diagrams, assembly procedures, and manuals. This process is the primary emphasis of analysis for this study.
3. Combination (Explicit-Explicit Knowledge Conversion):
   Students integrate individually developed assembly procedures and modularization ideas to reconstruct new standardized work processes systematically for assembly line production. These new processes include allocation of tasks to individual workstations and development of coordinated production workflows.
4. Internalization (Explicit-Tacit Knowledge Conversion):
   Students perform assembly tasks repeatedly based on newly developed procedures and line configurations. Through active experimentation and practice, the documented knowledge becomes embedded in their personal skills and experiences, consequently generating new tacit knowledge and practical insights.

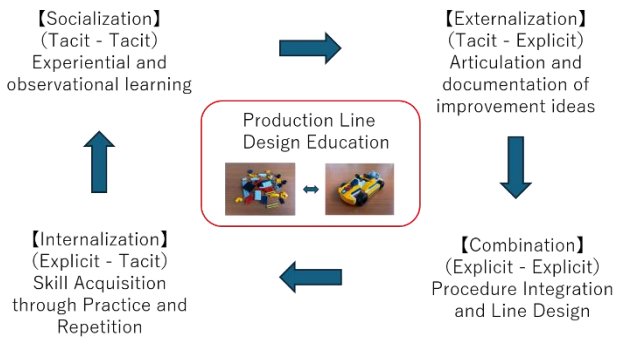


Fig. 1. SECI Model Applied to the LEGO Brick Assembly Experiment.

The correspondence between the SECI model and the LEGO brick assembly experiment provides a useful framework for understanding how experiential learning facilitates knowledge creation in production line design education. The study specifically examines the externalization process by which students transform experiential insights gained through production activities into explicit knowledge embodied in manuals, standardized procedures, and improvement proposals.

III. Experiment Method

The experiment was conducted during a three-week period with 42 mechanical engineering students. They examined a cell production system during the first week. During the second week, they investigated an assembly line production system. They prepared reports and shared their findings with other participants during the third week. A commercially available LEGO vehicle kit comprising 33 LEGO bricks was used for the assembly task. Students measured assembly times and implemented process improvements in a time-attack format under the following two production systems.

A. Cell Production System (Week 1)

Figure 2 shows that a single operator was responsible for the entire assembly process. Students first assembled the LEGO vehicle according to the manufacturer's instructions to learn the standard assembly procedure. Subsequently, each student independently optimized the arrangement of parts and assembly methods (Method in the 4M framework) and recorded assembly times over multiple trials. Through repeated practice and experimentation, students explored productivity improving and assembly time reduction.



Fig. 2. Experience of Cell Production System.

B. Assembly Line Production System (Week 2)

Teams of three to four students were formed. The assembly process was divided into six workstations. As presented in Figure 3, each team designed the assembly procedure collaboratively, including the assignment of assembly tasks to each workstation and the sequence of LEGO brick installation. The takt time, defined as the target production interval at each workstation, and the total production completion time were then measured. As a report assignment, students were required to develop an assembly procedure that incorporated consideration of line balancing, aiming at minimizing variations in workstation processing times and at improving overall production efficiency.



Fig. 3. Development of Assembly Procedures in the Assembly Line Production System.

C. Report and Reflection Activities

Following the experiments, students submitted a report during the third week. It included reflections upon and analyses of the following topics.

- Changes in all assembly times and variations among trials in the cell production system.
- Effectiveness of work improvement activities in reducing assembly time.
- Takt times at each workstation and their variations in the assembly line production system.
- Comparisons between cell production system and assembly line production system total assembly times.
- Effects of various production systems on product quality, operational efficiency, and production process management.

The student-produced reports, assembly manuals, and improvement proposals served as the primary data sources for analyzing the processes of tacit knowledge acquisition and explicit knowledge creation in this study.

IV. Results and Discussion

A. Analytical Framework Based on the SECI Model

To assess the improvement process of the entire class, reports submitted by all 42 students were analyzed by mapping the experiment activities to the four stages of the SECI model as described below.

- Socialization: The stage during which students acquired practical skills through repeated practice in the cell production system exercise and learned by observing the techniques and ideas of other groups and individuals (Week 1).
- Externalization: The stage during which students articulated tacit knowledge by describing their work-related insights and improvement ideas in written form during the cell production system exercise (Week 1).
- Combination: The stage during which students exchanged ideas related to production procedures and task allocation within their teams during the assembly line production exercise, thereby sharing and integrating knowledge (Week 2).
- Internalization: The stage during which students experienced actual assembly line production and learned to balance takt times through workload adjustment, transforming shared knowledge into personal skills and practical know-how (Week 2).

Analysis of the reports revealed a common pattern of development in the improvement processes of the participants. Students did not merely improve assembly speed through repetition. Rather, they developed practical knowledge related to production efficiency, workflow design, and line management progressively through iterative experimentation and reflection.

B. Externalization and Optimization of Tacit Knowledge in the Cell production System

With the cell production system exercise, students did not simply emphasize "working faster." Instead, they concentrated on creating systems that enabled assembly tasks to be performed efficiently, consistently, and without unnecessary motion or rework. Analysis of the students' written reflections indicated that they moved beyond intuitive trial-and-error approaches and generated sophisticated production-engineering practices from three major perspectives. These practices represent the externalization of tacit knowledge gained through hands-on experience.

- Ultimate Picking and Layout Optimization: Eliminating Cognitive and Motion Waste

At the initial stage, most students arranged parts according to simple criteria such as color or shape. However, as experimentation progressed, part layouts evolved into what many students designated as a "one-stroke flow arrangement," by which components were placed according to the assembly sequence. By arranging parts from front to back, or from left to right, in the exact order of use, students were able to consume parts sequentially while naturally creating an open workspace as parts were removed. This approach minimized hand movements and improved assembly efficiency. Numerous reports described efforts to optimize the spatial arrangement of components with the explicit goal of reducing unnecessary search time and motion. In addition, several ergonomic approaches were observed. For example, students intentionally placed thin LEGO pieces upside down (with the raised surface facing downward) to make them easier to grasp. Others developed a "slide-picking" technique, as illustrated in Figure 4, by which parts were slid across the desk surface and picked up from the edge rather than grasped directly from a flat surface. Furthermore, some students adopted three-dimensional spatial arrangements, shown in Figure 5, by positioning components in an upright orientation to improve visibility and accessibility. These strategies all demonstrate highly practical forms of tacit knowledge externalization aimed at eliminating both cognitive waste associated with

searching for parts and motion waste associated with inefficient hand movements. From the perspective of production engineering, these improvements reflect students' emerging understanding of workflow optimization, workplace organization, and ergonomic design principles. Such findings suggest that experiential learning can facilitate the effective transformation of intuitive operational know-how into explicit and transferable knowledge.



Fig. 4. Slide Picking.

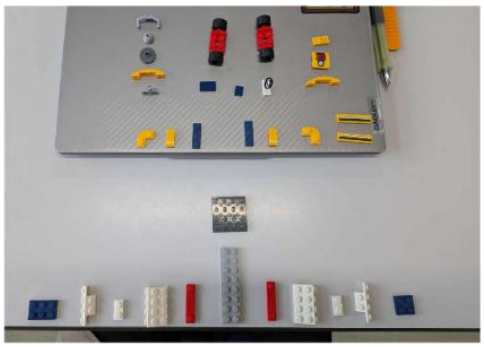


Fig. 5. Three-Dimensional Parts Arrangement.

- Thorough Utilization of Two-Handed Operations and Elimination of Holding Tasks

Asymmetric operations, for which one hand holds the product while the other hand installs components, were identified as a major source of time loss. To address this issue, students standardized assembly procedures that enabled simultaneous two-handed operations. As depicted in Figure 6, symmetrically paired components were arranged separately on the left and right sides of the workspace, allowing students to install both parts simultaneously using both hands. Furthermore, rather than holding the vehicle chassis in the air during assembly, students devised a method of using the worktable itself as a fixture. By keeping the base of the vehicle on the table and by pressing components into place from above with both hands, they were able to reduce unnecessary holding motions while improving assembly stability. This approach reflects a fundamental principle of production engineering: minimizing non-value-added motions while ensuring process stability and product quality. The students discovered that effective workpiece support and balanced two-handed operations were simultaneously able to reduce the operator's workloads, shorten assembly times, and improve assembly consistency. From the perspective of tacit knowledge externalization, these findings demonstrate how hands-on experience enabled students to transform intuitive operational insights into explicit assembly methods and standardized work procedures that can be shared and reproduced by others.

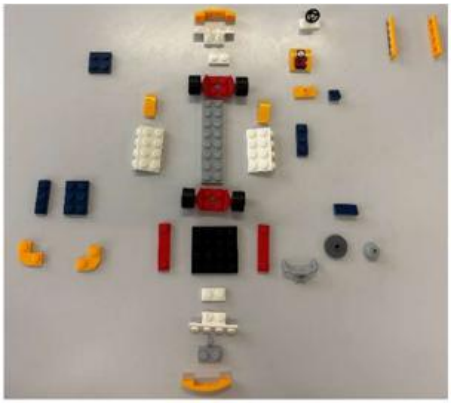


Fig. 6. Standardization of Two-Handed Assembly Operations Through Symmetrical Part Arrangement.

- Modularization and Mechanics-Based Process Design: Eliminating Rework and Assembly Failures

To prevent the collapse of partially assembled structures, which leads to defects and unnecessary rework, many students reexamined and reconstructed the assembly sequence provided in the original manual. Rather than assembling the entire vehicle as a single structure from the bottom upward, students widely adopted a modular assembly approach, as presented in Figure 7. By this method, major sections of the vehicle, such as the front, center, and rear portions, were assembled independently as separate modules (subassemblies), after which they were integrated into the final product. In addition, students developed two rational approaches for improving assembly stability based on their understanding of mechanical behavior, especially in terms of the wheel installation sequence. One approach placed the wheels at the final stage of assembly, thereby preventing structural collapse caused by the force necessary to press-fit the wheels onto the vehicle body. The alternative approach installed the wheels at the beginning of the assembly process, allowing the vehicle to remain stable and preventing the chassis from sliding across the work surface while upper components were being attached. These contrasting yet equally logical solutions demonstrate how students developed practical knowledge through direct experience of the physical characteristics and mechanical behavior of the product during assembly. Through repeated experimentation, they gained an embodied understanding of force transmission, structural stability, and assembly constraints. They subsequently transformed these insights into explicit and systematic assembly procedures. From the perspective of production engineering, this process represents the elimination of rework waste through improved process design and product handling. Moreover, it represents a clear example of knowledge externalization, in which tacit understanding derived from hands-on experience was converted into explicit knowledge in the form of standardized assembly methods and documented best practices.

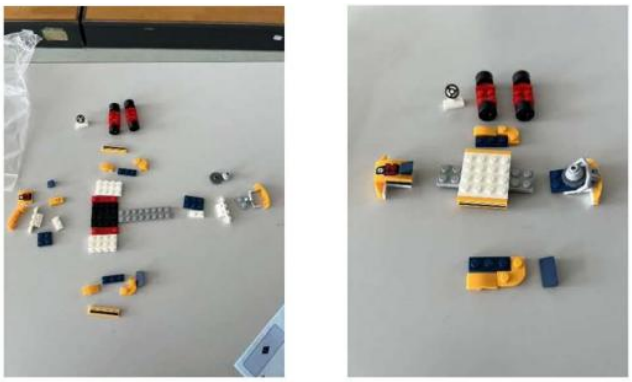


Fig. 7. Modular Assembly Approach Using Independent Subassemblies.

C. *Acquisition of a Systems Perspective Through Assembly Line Production*

For the assembly line production exercise, the assembly process was divided among team members. Standardized work procedures were established. Through these processes, students gained the following insights into optimization of the entire production system, rather than relying solely on individual skills.

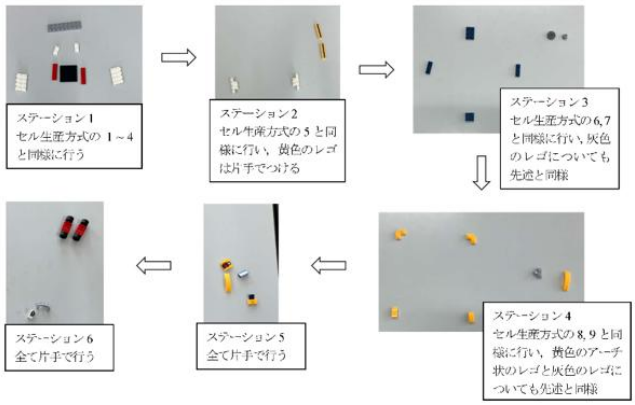


Fig. 8. Assembly Procedure Developed by Students to Eliminate a Bottleneck.

	作業内容	目安時間	写真
ステーション1	基盤の組立	10秒	
ステーション2	車のスポイラー部分の組立および細かい部品の取り付け	10秒	
ステーション3	フロント部分の組立	10秒	
ステーション4	その他部品の組立	10秒	
ステーション5	ステーション1～4で生成された部品の組立	10秒	
ステーション6	タイヤおよびハンドルの取り付け	10秒	

Fig. 9. Assembly Procedure Developed by Students with Consideration of Line Balancing.

• Line Balancing and Bottleneck Identification

Students experienced firsthand the difficulty of equalizing workloads (takt times) among workstations. They found that certain complex tasks, such as the assembly of small components, often became bottlenecks, and found further that even minor delays or mistakes at these stations generated waiting times throughout the entire production line. Based on actual production data, students analyzed the causes of such inefficiencies and proposed countermeasures. Many reports emphasized the importance of assigning highly skilled or dexterous operators to bottleneck stations and of redistributing tasks among adjacent stations to achieve better line balancing. These findings indicate that both the Combination and Internalization processes of the SECI model occurred during the exercise. Examples of assembly procedures developed by students through the Combination process are presented in Figures 8 and 9.

• Discovery of “Handover Loss” as a Source of Production Friction

One particularly interesting finding was the identification of handover loss, a form of non-value-added time that is characteristic of assembly line production. Regarding the LEGO product used for this study, which consisted of a few components, the time savings achieved through task specialization were sometimes outweighed by the time necessary to pass workpieces from one operator to the next. Consequently, some teams found that the cell production system, in which a single operator completed the entire assembly process, achieved shorter total assembly times than the assembly line system. Division of labor is theoretically expected to improve productivity, but the students discovered through analysis of empirical data that coordination and transfer losses can reduce overall efficiency in practice. This finding represents a clear example of the Internalization process, by which students transformed explicit knowledge about production systems into practical understanding through direct experience. It also demonstrates a key educational benefit of experiential learning: enabling students to recognize the gap separating theoretical efficiency and real-world operational performance.

V. Conclusion

Using LEGO bricks, a production line design experiment was conducted to analyze the knowledge creation process experienced by students during production system design and improvement activities from the perspective of the SECI model. The results showed that students did not simply perform assembly tasks as operators. Rather, through trial and error, they developed production engineering improvements independently, such as layout optimization, effective utilization of two-handed operations, and modularization strategies. Furthermore, they were able to articulate and systematize these insights as assembly procedures, layout diagrams, and improvement proposals.

It is noteworthy that the Externalization process, by which operational insights and know-how acquired as tacit knowledge were transformed into explicit knowledge, was observed clearly throughout the experiment. Students translated experiential learning outcomes into documented best practices that could be shared, communicated, and applied by others. This finding suggests that hands-on production line design activities can facilitate the conversion

of tacit knowledge into explicit knowledge effectively and thereby support knowledge transfer and knowledge creation in manufacturing education.

Future work will specifically examine accumulation and use of improvement cases and best practices identified through this study as educational resources. In addition, more realistic manufacturing constraints such as cost limitations, equipment failures, and production disruptions will be incorporated into the experiment environment to foster more advanced capabilities for production line design and problem solving. By promoting continuous interaction between tacit and explicit knowledge, such educational approaches are expected to contribute to the development of more effective manufacturing workforce training programs and to support the transfer of experiential expertise to future generations of engineers.

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