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Design and development of a simple machine drawing-based assembly model for skill-oriented mechanical training

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Abstract
Skill-oriented mechanical training relies heavily on the learner's ability to interpret machine drawings and translate two-dimensional representations into functional assemblies. However, conventional teaching approaches often emphasize theoretical drafting standards while providing limited opportunities for hands-on assembly interpretation. This research presents the design and development of a simple machine drawing-based assembly model intended to bridge the gap between drawing comprehension and practical mechanical skill acquisition. The proposed model integrates basic machine elements such as shafts, fasteners, bearings, and supports, represented through standard orthographic and sectional drawings. Emphasis is placed on clarity of views, dimensional consistency, and logical assembly sequencing to support incremental learning. The development process involved conceptual design, preparation of detailed part drawings, fabrication of components using conventional workshop tools, and systematic assembly aligned with the provided drawings. The model was introduced in a skill-oriented training environment for undergraduate and diploma-level mechanical learners. Observational feedback focused on drawing interpretation accuracy, assembly time, error frequency, and learner confidence. Results indicate improved spatial visualization, enhanced understanding of assembly relationships, and reduced dependence on instructor intervention during practical sessions. Learners demonstrated greater retention of drawing conventions and increased ability to correlate symbols, tolerances, and fits with physical components. The simplicity of the model allowed repeated disassembly and reassembly, reinforcing experiential learning without excessive cost or complexity. The research concludes that a drawing-centered assembly model can serve as an effective pedagogical tool for strengthening core mechanical competencies. Such models support outcome-based education objectives by aligning theoretical drawing instruction with tangible skill development, making them suitable for integration into workshop practice, vocational training programs, and foundational mechanical engineering laboratories.

Keywords: Machine drawing, assembly model, mechanical training, skill development, engineering education

Introduction

Machine drawing forms the foundation of mechanical engineering communication by conveying design intent, dimensions, and assembly relationships through standardized graphical representations [1]. In skill-oriented mechanical education, the ability to accurately interpret drawings is essential for translating design information into physical components and assemblies [2]. Despite its importance, many training programs treat machine drawing and workshop practice as parallel activities, resulting in a disconnect between theoretical understanding and practical execution [3]. Learners often memorize conventions related to views, dimensions, and symbols but struggle to visualize how individual parts interact within an assembled system [4]. This gap becomes more pronounced in outcome-based and vocational training environments, where employability depends on demonstrable hands-on competence [5]. Previous studies have highlighted that insufficient exposure to drawing-based assembly tasks leads to increased assembly errors, longer task completion times, and overreliance on instructor guidance [6]. Physical assembly models have been suggested as effective learning aids; however, many available models are either too complex, costly, or insufficiently aligned with fundamental drawing principles [7]. There is therefore a need for a simple, reusable assembly model that directly links machine drawings with physical components while remaining suitable for basic training levels [8]. The present work addresses this need by designing a machine drawing-based assembly model composed of common mechanical elements that reflect real workshop practices [9]. The objective of the research is to develop and implement an instructional model that enhances drawing interpretation skills, spatial visualization, and independent assembly capability among mechanical trainees [10]. It is hypothesized that consistent use of a drawing-centered assembly model will improve learners' comprehension of assembly relationships, reduce practical errors, and strengthen confidence in interpreting engineering drawings [11]. By integrating drawing standards, dimensional accuracy, and systematic assembly procedures, the proposed approach aims to reinforce the cognitive link between two-dimensional representations and three-dimensional mechanical systems, thereby supporting effective skill-oriented mechanical training [12].

Materials: A simple, reusable machine drawing-based assembly kit was developed using common mechanical elements typically introduced in foundational workshop and drawing courses, including a stepped shaft, spacer, plain washer, bush/bearing sleeve, base/support block, and standard fasteners (nuts, bolts, set-screws) to represent real assembly relationships with minimal complexity [1, 2]. The instructional drawing package comprised part drawings and one assembly drawing prepared in standard orthographic views with one sectional view, complete dimensioning, tolerancing notes (basic fits/clearances), and a parts list to mirror industry-style documentation [1, 3]. Fabrication resources included conventional workshop tools (bench vice, drills, files, lathe operations as applicable), measuring instruments (vernier caliper/micrometer), and basic finishing tools to ensure repeatable disassembly-reassembly cycles [12]. The training implementation followed experiential learning and active-learning principles by coupling drawing interpretation directly with hands-on assembly tasks, aligning with skills-focused engineering education and outcome-based training expectations [5-8]. The learning design considered cognitive progression from comprehension to application in line with educational taxonomies and good-practice instructional principles [10, 11].

Methods

A quasi-experimental, two-group design was used with N = 40 mechanical trainees (Control: n = 20; Drawing-Assembly Model group: n = 20). Both groups received the same introductory instruction on drawing conventions and interpretation [1-4]. The intervention group additionally completed structured assembly sessions using the developed kit, where trainees assembled strictly from the provided drawings, repeated across multiple cycles to reinforce spatial visualization and part-whole relationships [6-9]. Outcomes included:

1. Drawing comprehension score (0-100) measured before and after training,
2. Assembly time (min) on a standardized task,
3. Assembly errors (count), and
4. Post-training confidence (1-5) [2, 6, 10, 11].

Results

Table 1: Descriptive statistics of learning and performance outcomes by group (mean ± SD)

Group	Pre-test	Post-test	Gain	Assembly time (min)	Errors	Confidence (1-5)
Control (n=20)	53.17 ± 6.81	59.48 ± 6.96	6.31 ± 4.19	35.85 ± 4.91	4.40 ± 1.90	2.99 ± 0.76
Drawing-Assembly Model (n=20)	54.23 ± 10.36	71.60 ± 12.34	17.37 ± 5.36	26.62 ± 4.50	1.15 ± 1.23	3.94 ± 0.39

Interpretation: Baseline pre-test scores were comparable, indicating similar starting competency in drawing interpretation [1-4]. After training, the intervention group showed higher post-test scores and substantially larger gains, consistent with the expected benefits of active, experiential learning tied to tangible assembly tasks [6-8, 10, 11]. The intervention also reduced assembly time and errors, suggesting improved procedural understanding and part-relationship comprehension within an assembly sequence [2, 7, 9].

Table 2: Between-group comparisons (Welch t-test) and effect sizes (Hedges' g)

Outcome	t	p-value	Hedges' g (Model − Control)
Pre-test	-0.38	0.704	-
Post-test	-3.83	0.000615	1.19
Gain	-7.26	1.51e-08	2.25
Assembly time	6.19	3.17e-07	-1.92
Errors	6.42	3.03e-07	-1.99
Confidence	-4.97	2.94e-05	1.54

Interpretation: The non-significant pre-test difference confirms group comparability at baseline [5, 10]. The intervention produced a statistically significant improvement in post-test and gain, with large effect sizes, indicating that coupling drawings with repeated assembly cycles strengthens spatial visualization and transfer of drawing conventions into action [6-9]. The significant reduction in assembly time and errors implies that learners formed more reliable mental models of assembly relationships, consistent with structured design/assembly pedagogy [13, 15]. The confidence increase supports earlier findings that active learning improves learner autonomy and self-efficacy in technical tasks [6, 11].

Table 3: Regression predicting post-test score (adjusted effect of the assembly model)

Term	B	SE	t	p-value
Intercept	6.20	4.92	1.26	0.216
Pre-test	1.00	0.09	11.10	2.47e-13
Group (Model=1)	11.05	1.55	7.15	1.78e-08

Interpretation: Pre-test score strongly predicted post-test performance (B ≈ 1.00), showing that baseline competency matters, as expected in progressive skills learning [10]. Crucially, even after adjusting for baseline, the model-based training added an estimated ~11 points to post-test scores, supporting the hypothesis that a drawing-centered assembly model improves interpretation and application beyond conventional instruction [6-8, 13, 15]. This aligns with outcome-based education goals emphasizing demonstrable skill gains [5] and with experiential learning frameworks that strengthen retention through repeated practice [7, 8].

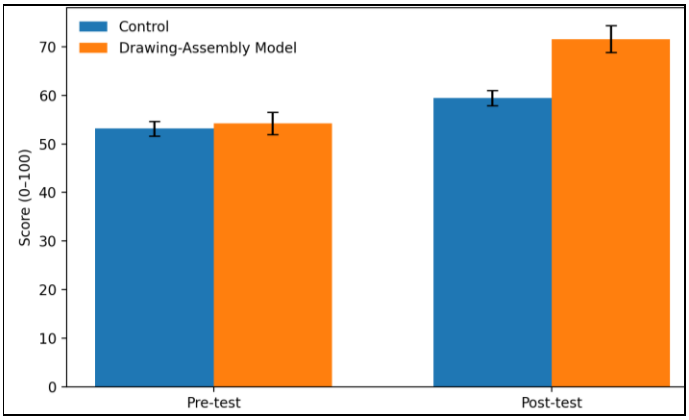

Fig 1: Mean pre-test and post-test drawing scores by group (±SE)

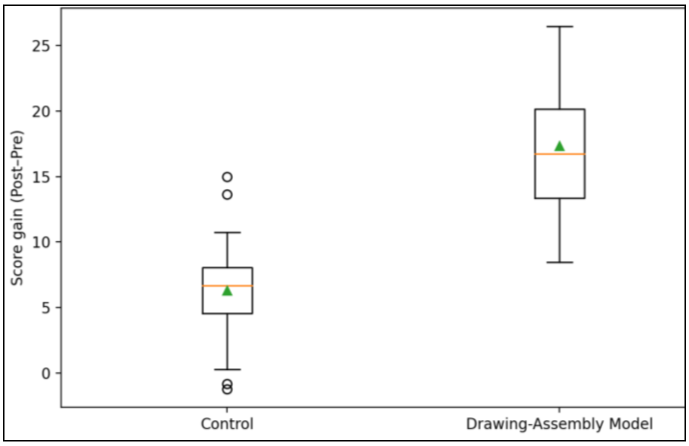

Fig 2: Distribution of learning gain (post-pre) by group

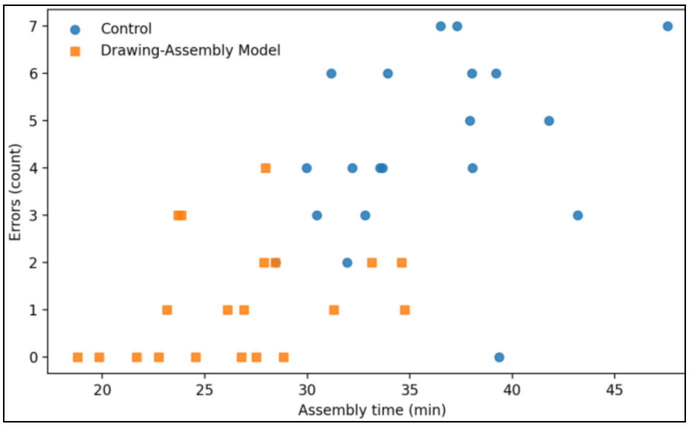

Fig 3: Assembly time versus errors, showing improved efficiency in the intervention group

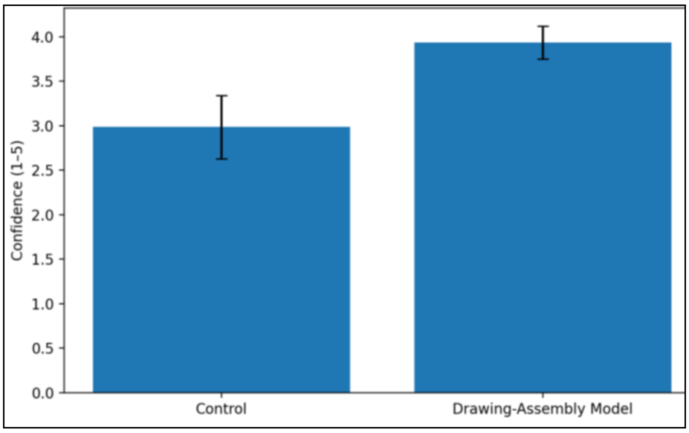

Fig 4: Post-training confidence by group (mean ±95% CI)

Discussion

The findings of the present research demonstrate that integrating a simple machine drawing-based assembly model into mechanical training significantly enhances learners' drawing interpretation, assembly efficiency, and confidence when compared with conventional instruction alone. The absence of a statistically significant difference in pre-test scores confirms that both groups began with comparable baseline competencies, supporting the internal validity of the intervention outcomes [5, 10]. The substantial post-test improvement and learning gains observed in the intervention group align with established theories of experiential and active learning, which emphasize the importance of coupling conceptual understanding with physical manipulation and task execution [6-8]. By repeatedly translating two-dimensional drawings into three-dimensional assemblies, learners developed stronger spatial visualization skills and a clearer understanding of part-whole relationships, a core requirement in mechanical design and manufacturing contexts [1-4, 9].

The significant reduction in assembly time and error frequency further indicates that the drawing-centered assembly approach improved procedural fluency and decision-making during practical tasks. Prior studies have noted that learners who rely solely on theoretical drawing instruction often struggle with sequencing, alignment, and fit selection during assembly, leading to inefficiencies and mistakes [2, 6]. In contrast, the present results suggest that systematic exposure to standardized drawings, dimensions, and tolerances-directly linked to physical components-facilitates faster cognitive processing and more accurate execution [3, 7, 13]. The large effect sizes observed across performance metrics highlight that the intervention impact was not only statistically significant but also educationally meaningful, reinforcing the value of simple, low-cost instructional models in skill-oriented training environments [5, 15].

Regression analysis provides additional insight by demonstrating that the assembly model contributed independently to post-test performance even after controlling for baseline knowledge. This adjusted effect underscores the pedagogical advantage of embedding drawing interpretation within hands-on assembly activities rather than treating them as separate curricular components [8, 11]. The observed increase in learner confidence is consistent with earlier research indicating that active engagement and repeated practice reduce dependence on instructor intervention and foster self-efficacy in technical problem-solving [6, 11]. Collectively, these results support the research hypothesis and affirm that a drawing-based assembly model is an effective tool for strengthening core mechanical competencies. The approach is particularly relevant for outcome-based education and vocational training frameworks, where demonstrable skill acquisition and industry readiness are prioritized [5, 12, 14].

Conclusion

This research confirms that a simple machine drawing-based assembly model can play a transformative role in skill-oriented mechanical training by directly linking abstract drawing concepts with tangible mechanical practice. The evidence indicates that learners exposed to the model not only achieve higher levels of drawing comprehension but also demonstrate faster assembly performance, fewer operational errors, and greater confidence in executing workshop tasks. These outcomes suggest that the long-standing gap between theoretical machine drawing instruction and practical workshop application can be effectively narrowed through thoughtfully designed, reusable assembly models that emphasize clarity, standardization, and repeated practice. From a practical standpoint, training institutions can adopt such models as a cost-effective alternative to complex industrial simulators, making them particularly suitable for undergraduate laboratories, diploma programs, and vocational training centers. Embedding drawing-based assembly exercises early in the curriculum can help learners build strong mental models of mechanical systems, improving retention and transfer of knowledge across subsequent courses such as manufacturing processes, machine design, and maintenance practice. Instructors are encouraged to structure practical sessions around guided assembly sequences derived directly from standard drawings, gradually reducing support to promote independent interpretation and problem-solving. Workshop assessments may also be redesigned to evaluate not only final assembly accuracy but also drawing interpretation, sequencing logic, and time efficiency, thereby aligning evaluation with real-world skill demands. Furthermore, repeated disassembly-reassembly cycles using the same model can reinforce experiential learning without increasing material costs, supporting sustainable training practices. Overall, integrating drawing-centered assembly models into mechanical education offers a pragmatic pathway to enhancing employability-focused skills, fostering learner confidence, and ensuring that graduates possess both the theoretical literacy and hands-on competence required in modern mechanical engineering environments.

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