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Implementing an Inquiry-Based Learning Model to Deepen Students' Conceptual Understanding

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Abstract

This study examines the effectiveness of the Inquiry-Based Learning model in enhancing students' conceptual understanding of the SMAW and GMAW welding processes, an area that remains underexplored in vocational education. The research addresses the gap between the development of procedural skills and the acquisition of conceptual reasoning by investigating whether inquiry-oriented instruction can promote deeper cognitive engagement. A quasi-experimental design was implemented involving two intact groups, with the control group receiving conventional teacher-centered instruction and the experimental group experiencing structured IBL activities. Data were collected through pretests, posttests, observations, and semi-structured interviews, and analyzed using paired-sample and independent-sample t-tests, ANCOVA, effect size calculations, and normalized gain measures. The findings reveal that the experimental group demonstrated a substantial and statistically significant improvement in conceptual understanding compared with the modest gains observed in the control group. The intervention produced a very large effect size and a medium-high normalized gain, indicating strong learning effectiveness. Students exposed to IBL were better able to analyze parameter interactions, interpret defect mechanisms, and connect theoretical principles with laboratory outcomes. Overall, the study provides strong empirical evidence that Inquiry-Based Learning is a highly effective pedagogical approach for strengthening conceptual mastery in welding technology and should be considered for broader integration into vocational curricula.

Introduction

Technical and vocational education has come to play a central role in the national strategies of vocational development of the workforce, modernization of industries and economic competitiveness. In many jurisdictions, the welding industry is at the forefront of the development of infrastructure, production, and engineering processes. With the increasing demand of the highly skilled welders, vocational institutions are under increasing pressure to ensure that upon graduation, the graduate is not only able to perform the task in a practical manner, but is also able to have sound conceptual understanding of the complex welding procedures. The modern technologies of welding, especially arc welding, like Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW), require the operators of such equipment to combine the theoretical knowledge with the practical decision-making in real time (Kunar & Mandal, 2025; Purohit & Parkhi, 2016; Buang et al., 2024). The conceptual

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understanding empirical research has shown to play a major role in the quality of weld, minimization of defects, and operational safety (Olalerea et al., 2023; Liu et al, 2024; Jatavallabhula et al., 2025). In turn, the ideas of teaching that help to strengthen the conceptual knowledge cannot be ignored in order to improve the quality of the welding training and, finally, the competence of the workforce.

Recent pedagogical research on technical education highlights a shift in traditional pedagogical approaches towards more participatory and student oriented pedagogical models. Educational books are becoming more supportive of the claim that passive modes of learning, such as lecturing, demonstrating, and repetitive procedures cannot help in developing the rich conceptual frameworks essential to technical subjects (de Resende & Duarte, 2025; Mobaraki, 2025). Considering the fact that welding is a process that involves thermodynamic, metallurgical, electric principles, one can infer that the student should develop an integrated knowledge that will justify diagnostic rationale, troubleshoot, and adaptive decision-making. The need to create instructional models that offer a bridge between the theoretical-practical gap has hence escalated. Several researchers argue that student centered learning encourages analytical thinking, conceptualization, and other advanced skills of thinking, which are important in acquiring welding skills (Jatavallabhula et al., 2025; Dada et al., 2023; Anthonysamy et al., 2024; Nykyporets & Chopliak, 2023). Among the growing body of studies, Inquiry-Based Learning (IBL) has emerged as a powerful pedagogical tool that can overcome these didactic issues.

Although the importance of conceptual knowledge is quite obvious, traditional teacher-oriented training still predominates in most welding classes. This teaching model usually focuses on procedural precision by demonstrating by the instructor and then reproducing by the student with minimum concern of conceptual rationale (Schulz, 2024; Martin & Graulich, 2023; Shure & Liljedahl, 2024). As well as these techniques are effective in the development of the psychomotor competencies, in most instances they do not explain the underlying reasons of a particular welding results or how changes in parameters affect the quality of the welds. As a result, the learners can end up being reliant on routine and not coping up with new welding conditions or it can happen, the defects. The problem here, however, is that traditional methods provide limited chances to the students of studying, investigating, and considering welding phenomena, factors that are important to enhance learning of the concepts deeper and retention of knowledge over the long term (Kilbrink et al., 2022; Mackiewicz, 2022; Muzata et al., 2024; Fu et al., 2024).

To address these challenges, there is an increasing body of research that suggests the incorporation of active learning into the learning of welding. These strategies often include problem-solving exercises, group learning, and experimental works that force the students to work with the variables of the processes directly and with real welding situations (Jalinus et al., 2020; Schmidt et al., 2011). Empirical research in the engineering and vocational education shows that active learning methodology can prove to be instrumental in conceptual understanding by motivating the learners to attribute hypotheses, modify parameters of tests, and make conclusions based on them based on observation and analysis (Ruijuan et al., 2023; Nurbavliyev et al., 2022; Lombardi et al., 2021). These results indicate that active learning does not just enhance the level of theoretical knowledge, but it also increases the ability of learners to put learning into practice. However, there is a lack of active learning in vocational welding programs, which can also be explained by institutional inertia, a lack of resources, and the reluctance of educators to use active learning.

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Inquiry-Based Learning (IBL) is one of the models of active learning that have gained some recognition due to its strong theoretical foundations and proven effectiveness in the field of STEM (Ješková et al., 2022). IBL places students in the centre of the learning process where they develop questions, explore problems, and develop explanations based on empirical evidence. According to the empirical studies, IBL promotes a better level of analytical reasoning and metacognitive skills, as well as conceptual integration, which makes it particularly relevant to technical disciplines, where the inquiry and experimentation are crucial elements of professional practice (Kotsis, 2025). Concerning the education in welding, IBL provides students with organized chances to control welding factors, monitor the consequences of electrical and mechanical changes, discuss the features of a weld bead as well as consider the scientific basis. This interaction brings about a deep understanding of cause and effect allowing students to go beyond the levels of procedural imitation to actual conceptual mastery.

Past research that has used IBL in technical fields continuously documents positive results of student learning outcomes. An example of this is in electrical engineering education research has shown that inquiry based tasks increase the ability of students to trouble shoot and think in terms of how a system works (Riantoni et al., 2025; Liao et al., 2023; Chu et al., 2021). Equally, IBL in mechanical and manufacturing teaching has been demonstrated to promote conceptual knowledge of material behavior, and thermal processes, and machine behavior (Brown, 2024; Lino Alves & Duarte, 2023). These results indicate that the model can be adapted to those disciplines in which students are required to combine theoretical knowledge with practical experimentation - those conditions that closely replicate the learning environment in the welding laboratories. However, amidst the encouraging findings, empirical studies involving use of IBL in the context of welding education are few. Very few studies investigate its impact on the conceptual understanding of arc welding processes; hence, there is a gap in literature as to its effectiveness compared to the traditional methods of instruction.

A further analysis of the literature devoted to conceptual understanding in welders shows that there are a number of gaps in current research. Most of the earlier studies have focused on the development of procedural skills or the effectiveness of training based on simulations and relatively little has been done to focus on conceptual reasoning or cognitive outcomes. Moreover, researches that have used active learning practices often lack serious experimental designs of do not measure conceptual improvements with validated assessment tools. The limited number of studies that examine the conceptual comprehension in the field of welding highlights the necessity of the studies with a solid methodological foundation that compares innovative instruction, like IBL, with conventional methods. Also, there is little literature that has explored conceptual learning between SMAW and GMAW processes simultaneously, although they have become predominant in vocational welding institutions. This gap underscores the need to conduct research which has a systematic way of assessing the influence of inquiry based instructional strategies on students conceptual knowledge of arc welding technologies.

Methods

The research design that was used in this study was a quasi experimental research design to determine whether the conceptual knowledge of students in the SMAW -GMAW welding process can be enhanced with the help of an Inquiry based learning model. The quasi experimental design was chosen on the basis that educational interventions at realistic classroom settings seldom permit random allocation and in the intact classes an obligation to preserve intact classes normally exists owing to administrative and curricular limitations. According to Cook et al. (2002) quasi-experimental designs are a strong methodological option

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to conclude the causal relationship when the researcher can prove the group equivalence, control the extraneous factors and explain the baseline differences by utilizing suitable methods of analysis. The design adopted in the current study would compare one group that would have undergone an Inquiry-Based Learning intervention to the other group that would have undergone the conventional teaching approach where the researcher would be able to isolate the pedagogical impact of inquiry based learning on welding related conceptual development.

This research was carried out in a vocational high school where they are studying welding technology, which has both theoretical and practical training of SMAW and GMAW. The reasons as to why these two welding processes were assigned are due to the fact that these two represent some of the key areas of competence in the welding education field and that they bear conceptually sound material in terms of polarity, heat input, arc stability, and metal transfer characteristics and safety considerations. Previous studies on vocational STEM learning underline the fact that a learner has to possess a conceptual knowledge to facilitate correct selection of parameters, detection of welding anomalies, and subsequent adjustment of the process when the learner is involved in a practical activity as pointed out by Prince and Felder (2007). Hence, this field offers an active environment to investigate the role of Inquiry-Based Learning in facilitating conceptual learning and enhanced thinking.

The subjects were two classes, which were already existing, of similar sizes, previous educational success, and familiarity with the welding practices. There was one class, which was considered the experimental group and which was provided with the Inquiry-Based Learning intervention, and another class which was taken as the control group and which provided them with the conventional lecture-driven and demonstration-based learning. Even though the method of randomization could not be applied, the comparability of groups was made with the help of pre-intervention testing and institutional files, which proved that they had similar backgrounds and competency levels. By so doing, it was possible to guarantee that any differences in learning outcomes could possibly be explained by the intervention and not by existing differences. Both groups were taught by the same instructor to reduce the teacher related differences and the learning environment, lab equipment, instructional time and material were also held constant across groups in order to maximize internal validity.

In the quasi-experimental model, data-gathering involved pre-tests and post tests, which were developed to evaluate the conceptual knowledge of the students on Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW). Multiple choice questions testing main principles and short answer questions, where students were asked to explain causal reasons to welding defects, parameter interrelations and behaviour of processes, were included in the instruments. The process of test development was based on the recommendations provided by Aiken (2003), which meant that every item represented the salient conceptual dimensions and the content was tied to the welding education requirements. The content validity was determined with the help of expert opinions, two welding instructors and vocational pedagogy specialist. The reliability was ensured through pilot testing and Cronbach alpha was calculated on the multiple-choice questions whereas the rubric employed in the scoring of short-answer responses was confirmed through the inter-rater reliability process with two assessors. Such a strict development process resulted in an assessment instrument that was able to identify substantial conceptual delivers that could be attributed to the instructional intervention.

The intervention in the form of inquiry based learning applied to the experimental group was six weeks of instructional time and included the main stages of inquiry reported by Pedaste et al. (2015). A real-world problem or phenomenon related to welding (such as porosity, spatter,

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beads not forming, or arc instability) was presented to the students, and they needed to interpret the conceptual information. Both of them worked together to develop investigable questions, hypotheses, and small-scale experiments that manipulated experimental variables, including current, voltage, electrode type, wire-feed speed, and shielding-gas compounds. In the trials undertaken during the welding courses, students noted the process behaviours, the bead characteristics, electromagnetic measurements and safety observations. Later discussion provided an analysis of various problems in terms of discrepancy between the anticipated results and the actual results, bridged empirical evidence with theory, and guided reflection lessons conducted by the instructor. These tasks were to promote strong conceptual interaction and to facilitate knowledge-restructuring process described by Bransford et al. (2000) when learners combine practical observations with the principles in the background of the welding field.

On the other hand, the control group used a traditional teaching paradigm that involved the teacher explanation and demonstration, as well as guided practice using the established welding parameters. The students were instructed to mimic the instructor-model procedures as opposed to formulating their own questions and coming up with their own trials. Even though this method is typical of vocational education, studies have shown that it tends to limit conceptual reasoning and autonomy of troubleshooting. On a comparative basis of the two methods of instruction, the study aimed to assess the particular role of inquiry oriented methods of instruction in promoting conceptual knowledge.

The qualitative data were gathered to provide a greater understanding of the processes of learning that were prompted by the intervention. The classroom observations were implemented at the main instructional sessions to record the type of student interaction, including the development of a hypothesis, conversation-based problem-solving, and the use of the conceptual reasoning when students engaged in welding activities. The interpretation of observation notes was done with the analytical perspectives postulated by Hmelo-Silver et al. (2007) thus highlighting pointers of inquiry-based cognitive processing. The semi-structured interviews of the chosen students provided supplementary information on their developing conceptual knowledge, their views on the process of inquiry and their opinions on the welding problem that they have to face when experimenting. These qualitative data introduced some explanatory layer to the quantitative results and as such, this is in line with Greene (2007) ascertaining that in mixed-method research, complementarity is applied in the area of quasi-experimental designs.

The data analysis was started by the descriptive statistical analyses of the pre-test and post-test score in both groups. Paired-sample t -tests were used to test the hypothesis that significant learning gains were achieved in each group, and independent-sample t -tests were used to test the hypothesis that greater learning gains were achieved by each group. Analysis of covariance (ANCOVA) was also applied when pre-test scores showed that there was a risk of imbalance in the baselines so that comparisons of post-test results could be adjusted, as well as by considerations of the methodology by Field et al. (2018). The effect sizes were determined to determine the intensity of the intervention effect, hence providing a clinically significant meaning of the statistical results. These analytical techniques were facilitated by the quasi-experimental structure because it offered clear baseline and outcome measures in the instructional conditions. Thematic analysis, as defined by Braun and Clarke (2006), was used in the qualitative analysis of the data because it allowed revealing common themes in regards to conceptual integration, inquiry-based reasoning, and changes in the decision-making of students regarding welding.

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Results and Discussion

The findings of this paper give an all-inclusive analysis of how the Inquiry-Based Learning model impacted the conceptual knowledge of the students regarding the processes in SMAW and GMAW welding. The quantitative findings supported by qualitative information show the degree to which the inquiry-based instruction led to the conceptual growth, learning outcomes, and cognitive activity of students in comparison with the traditional teacher-centered instruction. The results are presented as per the analytical framework developed in the methodology starting with within-group comparisons, then between-group differences, and finally evaluating the magnitude of the effects before these results are aligned with qualitative evidence supporting the statistical results. All the subsections integrate the relevant theoretical underpinnings, such as constructivist views, presented by Bransford et al. (2000) and principles of inquiry-based learning, laid out by Pedaste et al. (2015), which allows these studies to have an interpretative depth that fits the purpose of this quasi-experimental study.

Pretest Posttest Comparisons in the Control Group

Table 1. Paired-Sample t-Test for Control Group (Pretest–Posttest)

Statistical Component	Value
N	35
Pretest Mean	50.40
Posttest Mean	55.97
Mean Difference	5.57
Std. Deviation of Difference	0.730
Std. Error	0.123
t-value	45.166
df	34
Sig. (2-tailed)	0.000

The outcomes of the paired-sample test (t) of the control group suggest that the score of the students was statistically significant after receiving conventional education ($t \succ 45.166$, $p \stackrel{\star}{=} 0.000$). The result of this finding is that the students had an experience of learning throughout the period of instruction. Nevertheless, the scale of the amelioration 5.57 points on average, points to the fact that the conceptual progress made was minimal. The low standard variation of the differences (0.730) shows that the majority of the students made a gain that was of the same small amount and thus proves the point that traditional teaching caused similar but slight gains. These results are typical of the teacher-centered methods, in which learning is usually implemented via repetition and passive consumption of content. The low N -gain score (0.112) places the learning effectiveness firmly in the low bracket, which would mean that traditional instructional strategies failed to inspire deeper conceptual knowledge on welding processes of arc stability, heat input, or formation of defects. Comprehensively, although the traditional teaching produced quantifiable improvements it was not sufficient to bring about significant conceptual changes.

Pretest Posttest Comparisons in the Experimental Group

Table 2. Paired-Sample t-Test for Experimental Group (Pretest–Posttest)

Statistical Component	Value
N	35
Pretest Mean	51.54
Posttest Mean	75.46

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Mean Difference	23.91
Std. Deviation of Difference	2.104
Std. Error	0.356
t-value	78.221
df	34
Sig. (2-tailed)	0.000

The paired-sample t -test (t = 78.221, p = 0.000) showed that the experimental group had a highly significant improvement in conceptual understanding. The overall improvement of 23.91 points is quite high, indicating that the Inquest based Learning (IBL) intervention has fundamentally changed the mastering of the SMAW-GMAW concepts by students. The standard error (0.356) is relatively small, which means that this enhancement was not specific to one participant and implies that most learners gained significantly through the use of the IBL approach. This sharp increase is an indication of the power of inquiry-based teaching, which encourages students to create questions, test hypotheses, analyze the interactions of parameters, and make conclusions based on real-life applications of welding. This kind of engagement facilitates more conceptual reorganization so that learners move beyond superficial understanding of substantive mastery. The score of N-gain (0.494) is between medium and high indicating that there is high degree of learning effectiveness and this proves that IBL model has helped students in understanding the principle underlining the performance of welding.

Between-Group Comparisons of Learning Gains

Table 3. Independent-Samples t-Test for Learning Gains (Control vs Experimental)

Group	N	Mean Gain	Std. Deviation	Std. Error
Control	35	5.57	0.730	0.123
Experimental	35	23.91	2.104	0.356

The findings in Table 3 prove that there is a significant difference in the learning outcomes between the control and experimental groups. Control cohort students who were taught through conventional methods that involve teacher-centered instructions just accumulated a small mean of 5.57 points. This minor and comparatively monotonous increase is an indication that the old and mostly conservative ways of pedagogy mainly support the process of repetition rather than the development of deeper insight into the conceptual plane. This would be expected of the nature of the traditional teaching process, whereby students are usually made to take the prescribed steps without necessarily exploring into the foundations of the SMAW- GMAW welding process. As a result, their conceptual growth is still low as indicated by the low scores in gain. On the other hand, the experimental group of students who underwent Inquiry-Based Learning (IBL) reached a significant mean of 23.91 points, which is much higher than the improvement of the control group. Such a strong enhancement shows that IBL is effective in letting the learners actively investigate the variables of welding, develop and test hypotheses, interpret findings, and ponder on conceptual connections. The major gap in the mean gains of the groups (18.34 points) proves the better influence of inquiry-based teaching on the mastery of the concepts. Students improved their performances and acquired better reasoning skills and problem-solving skills as well as a deeper insight into the impact of welding parameters on performance therefore proving that IBL fosters meaningful learning and transformative learning.

Table 4. Summary of Independent-Samples t-Test Statistical Components

Statistical Component	Value

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t-value	48.612
df	68
Sig. (2-tailed)	0.000
Mean Difference	18.34

The statistical elements in Table 4 show the very significant difference of the learning gains of the control and the experimental group. The fact that the t -value is incredibly high (48.612) implies that the performance of the two groups is significantly different, and it is far beyond the norm of statistical significance. The significance value (p = 0.000) confirms the assumption that such difference is not a result of random chance with a degree freedom (df) of 68 indicating that the two independent samples are equal in size. These findings confirm the conclusion that cause of differences in conceptual understanding is instruction method used, as opposed to natural variation between students. The statistical strength of these values shows a very strong reliable effect that can be caused by the instructional intervention.

The average difference of 18.34 points also represents the extent of the effect caused by the Inquiry-Based Learning (IBL) model. This significant difference substantiates the fact that the conceptual improvement of this experimental group was significantly high as opposed to the control group. This is a strong mean difference that is not common in educational research and it at the same time indicates not just statistical significance but also practical and educational significance. It means that IBL was superior to marginal improvement of learning; it fundamentally changed the ability of students to comprehend, analyse and apply welding principles. The results of these observations highlight the usefulness of inquiry-based teaching in promoting more profound cognitive engagement, reorganization of concepts, and permanent learning of complex technical content.

ANCOVA Results Controlling for Pretest Differences

Table 4. ANCOVA for Posttest Scores (Controlling Pretest)

Source	SS	df	MS	F	Sig.
Pretest (Covariate)	41.52	1	41.52	6.12	0.016
Group (Treatment)	1926.35	1	1926.35	284.34	0.000
Error	447.18	66	6.77		

The covariance analysis provided further evidence that shows the effectiveness of the Inquirybased Learning (IBL) intervention. Adjusting the pre-test scores, the treatment effect was still significant ($F(1, n -1) = 284.34$, $p <.001$). In its turn, the significant increase in post-test scores in the experimental and control group cannot be explained by the difference in the baseline knowledge and can, instead, be explained by the direct effect of the instructional strategy. The pretest covariate itself was significant ($F = 6.12$, $p =.016$) which means that initial knowledge had a small but statistically significant effect in post test performance. However, the preponderance of treatment effect is clear since it has an extremely large F-value. These results point to the fact that IBL has always generated significant returns in the whole sample regardless of the level of initial knowledge that the participants had at the beginning of the experiment hence the results support a causative relationship between the intervention and the improvement in the conceptual understanding.

Effect Size

Table 5. Effect Size Analysis

Comparison	Cohen's d	Interpretation
Control (Pre–Post)	1.40	Large Effect

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Experimental (Pre–Post)	8.51	Very Large Effect
Control vs Experimental (Gain)	10.36	Huge Effect

Effect-statistics also prove the substantive effect of the instructional modalities. Control group had a Cohen d of 1.40 which is large effect; but this should be put into perspective considering the low pre-test basis scores. On the contrary, the d of 8.51 in the experimental group is very large, which is an indication of a radical change in the outcomes of learning. The gain-score comparison of groups provided an effect size of 10.36 and this value highlighted the significant difference in efficacy of the two types of instruction. Such high effect sizes are not common in the research of the educational field, which underscores the significant impact of IBL. These numbers demonstrate that the differences observed are not limited to statistical significance, but they are large, significant, and educationally relevant. Thus the results prove the argument that inquiry-based pedagogies are significantly superior to traditional methods in promoting conceptual reasoning, analytical thought as well as the synthesis of theoretical and practical information in the context of welding training.

N-Gain Effectiveness

Table 6. N-Gain Effectiveness

Group	Pretest Mean	Posttest Mean	N-Gain	Category
Control	50.40	55.97	0.112	Low
Experimental	51.54	75.46	0.494	Medium–High

The normalized gain scores further illustrate the contrasting effectiveness of the two instructional methods. The control group's N-gain of 0.112 categorizes its learning improvement as low, confirming that conventional instruction led to minimal conceptual advancement. Students may have improved slightly, but their learning largely remained at the level of procedural repetition rather than conceptual mastery. In contrast, the experimental group's N-gain score of 0.494 falls within the medium-to-high category, demonstrating that Inquiry-Based Learning facilitated meaningful conceptual growth. Students became more adept at explaining welding behaviors, identifying causes of defects, and connecting laboratory outcomes to theoretical principles. This intermediate-to-high level of conceptual acquisition reflects the strength of inquiry processes in stimulating deep learning, problem-solving abilities, and higher-level thinking skills.

Implications of Inquiry-Based Learning on Welding Concept Mastery

The results of the current study give strong empirical data that the application of the Inquiry-Based Learning (IBL) methodology produces a significantly larger effect on the conceptual knowledge of students in learning SMAW- GMAW welding processes than traditional teaching. Although both teaching methods yielded statistically significant pre-post improvement, the amount of the improvement was quite different. This difference highlights some basic pedagogical distinctions between teacher-centered and student-centered learning contexts (Lancaster, 2017). In particular, the findings indicate the ability of IBL to provoke more profound thinking, encourage critical thinking, and lead to the reorganization of the previous knowledge three factors that are key to mastering the complex technical material. The strong mean gain difference between groups shows that conceptual learning within technical and vocational education is very sensitive to instructional practices which prefigures inquiry, experimentation as well as reflective thought.

The major point of findings is that the students in the experimental group were also more participatory on conceptual aspects of welding instead of the acquisition of procedural steps.

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In conventional approaches to welding education, a lot of learning by students is operational, i.e., it is focused on what one needs to do to get it right. Although this set of skills cannot be denied, technical competence also relies on knowledge of underlying principles of heat input, modes of metal transfer, arc characteristics, polarity effects, and shielding gas behavior. The IBL environment helps students to attempt to make sense of such phenomena by motivating them to make hypotheses, manipulate variables and explain what they observe (Pei, 2025). These findings are in line with the constructivist learning theory, which argues that effective comprehension arises when learning occurs as learners engage in constructing knowledge by learning through work and discussion as opposed to learning passively as a recipient of information. The much greater conceptual understanding advances in IBL group, therefore, reflect that cognitively active learning is especially fruitful in technical courses that require the combination of theory and practice.

The fact that the effect sizes that were recorded in the experimental group are extraordinarily large, further supports the claim that IBL is more than just marginally more effective but is much more effective in creating meaningful understanding. This concurs with the current studies in engineering and STEM education, which repeatedly show that inquiry-based, project-based, and problem-based delivery models are more effective than traditional lecture-based models to develop more profound understanding and transfer of knowledge. The present results apply these observations to the sphere of welding education, which has always been dominated by the methods of apprenticeship and demonstration. This study will break a long held belief that welding education should be guided by rote and demonstration as a teaching method by proving that conceptual reasoning in welding can be reinforced considerably using inquiry-oriented interventions.

Introducing evidence of how the inquiry-based methods significantly contribute to conceptual understanding, this study adds to the number of studies supporting the importance of pedagogical strategies that focus on active learning and critical thinking. It demands the reconsideration of the conventional teaching models and asks teachers to incorporate the aspect of inquiry as a primary element of technical teaching. Eventually, such findings highlight the need to encourage educational stakeholders to shift focus towards more instructional practices that facilitate the acquisition of profound, transferable knowledge over the accumulation of superficial skills.

There is one more dimension that should be considered, and it is the effect of student autonomy and agency on Inquiry-Based Learning (IBL) situations. The nature of inquiry environments, in turn, offers learners with chances to take control of the question under inquiry, process findings, and develop conclusions. This kind of involvement might explain the high levels of gains recorded in the current research since autonomy has been put in place to increase persistence, motivation, and depth of thought process. When students create their own experiments, such as changing existing settings or changing speed of travel with the purpose of observing bead formation, they are better placed at creating conceptual connections between theory and practice. This is of particular concern in welding where even minor changes in the parameters may have significant impacts on the weld integrity, the development of defects, and thermal properties. Its results indicate that IBL can be used to design such critical analytical skills because it prompts the students to pay attention, doubt, and think in the manner that simulates the thoughts of professional welders and inspectors.

The study outcomes have important implications in the practice of assessment in vocational education. The alive contrast between experimental and control groups highlights the importance of the conceptual understanding, not only of procedural accuracy or practical

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performance. Despite the fact that the quality of weld and technical proficiency cannot be replaced as a by-product, the conceptual understanding has a drastic impact on the ability of a student to troubleshoot anomaly, learn in new welding conditions, and understand complex processes. The results achieved in the experimental group suggest that evaluation systems that involve conceptual measures, including problem-solving cognitions, scenario-driven queries, parameter-interpretation tasks, etc. could be more indicative of the comprehensiveness of learning that is induced through inquiry-based teaching methods.

Although the findings of the study are quite strong, there are also challenges that are related to the implementation of IBL in the field of technical education that are also mentioned in the study. Inquiry activities require greater instructional planning, classroom management skills, and flexibility, in comparison with traditional pedagogies. Teachers need to make assignments that are structured and open-ended enough, and predict possible misunderstandings and lead the discussion without offering answers too quickly. In addition, vocational trainers often have time and budget limitations, which may hinder the process of longer inquiry cycles or customized assistance. These problems support the need of professional development programs that would prepare instructors with pedagogical skills needed to shift the demonstration based teaching model to the facilitation of inquiry in learners.

According to the findings of the research, the prior knowledge had a statistically significant but a small impact on the learning outcomes as per the ANCOVA analysis. Even though the pre-test scores were involved in the forecasting of the post-test performance scores, the instructional approach had an even stronger impact. As a result, the data indicate that students of all levels of conceptualization tend towards an inquiry-based learning (IBL), which is independent of the starting level of knowledge. Such a conclusion is especially relevant in the context of vocational classrooms, which are traditionally comprised of scholars with different academic histories and levels of preparedness. The found increase in the outcomes of the participants after the introduction of IBL highlights its ability to provide benefits that can facilitate various learning preparations.

Practically, the results emphasize the importance of intentionally integrating inquiry-based pedagogies in welding educational programs. Integration of this kind can entail the organization of guided experiments, parameter-testing activities, the design of reflective exercises, and collaborative discussions during welding laboratory sessions. This evidence confirms the argument that conceptual teaching need not remain in a secondary place compared to the acquisition of technical skills; on the contrary, the two aspects support each other when inquired instruction is applied to them. Conceptual knowledge will improve the precision of welding jobs by students, and the technical practice will offer the practical background on which students can solidify conceptual knowledge.

Curriculum designers and policymakers also have implications towards the study. With vocational education systems across the world shifting to competency-based models, these results support the proposal to have more competencies associated with conceptual reasoning in national qualification frameworks. Inquiry-based works can be well matched to the competency-based learning as they measure the ability of learners to think, solve problems, and use knowledge in real-life situations. To improve learning outcomes and workforce preparedness, the policy makers ought to integrate enquiry based modules in the national welding qualification requirements.

Lastly, the results should be interpreted considering the limitations of the study. The study was carried out using a fairly limited sample and in one institutional setting, which may limit its extrapolation. Also, the analysis aimed at purely conceptual knowledge, as opposed to

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psychomotor skill competence. Future studies may focus on determining whether IBL is not only more effective in improving conceptual knowledge but also in improving the quality of welds, detecting defects, or troubled shooting abilities in actual laboratory environments. Future longitudinal studies can also address the question of whether the conceptual benefits incurred through the application of IBL transfer to better workplace performance or faster skill development during the apprenticeships, and thus add to the understanding of the field of how inquiry-based pedagogies impact on the cognitive and practical aspects of technical competence.

Conclusion

This study demonstrated that the Inquiry-Based Learning (IBL) model significantly exceeded traditional teaching in developing conceptual learning in students of SMAW-GMAW welding procedures. The experimental cohort resulted in major gains, which were represented through higher post-testing scores, higher learning gains, and larger effect sizes. These results indicate that IBL would help in promoting better cognitive work, improved critical thinking, and more abundant combination of theoretical and practical ideas in welding. On the other hand, the improvement in the control group was rather modest, which means that conventional, teacher-oriented approaches are still limited to the stimulation of conceptual growth. Findings support the growing body of literature that supports the idea of student-centered pedagogies in technical and vocational education, in which inquiry, experimentation, and reflective thinking play a crucial role in long-term mastery. The implications in the study highlight the need among curriculum designers, vocational educators and policy makers to incorporate inquiry-based strategies in the welding education systems. IBL helps students to tackle more problem solving challenges in the industrial environment by enabling students to actively question welding phenomena and associate variations of parameters with material behavior. Despite the fact that the given study was limited to one institution and did not focus on the conceptual results to an extent, the research results offer a solid foundation on the future study on the effects of IBL on psychomotor skills, workplace flexibility and knowledge retention in the long term. Future studies are needed to explore broader application in more diverse work environments and determine how inquiry-based methods can be integrated into competency-based curricula in a more systematic way to complement both theoretical knowledge and practical welding skills.

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