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Technological learning in the transfer of knowledge from Malaysia and Switzerland to the manufacture of photovoltaic modules in Brazil.

Technological learning in the transfer of knowledge from Malaysia and Switzerland to photovoltaic module manufacturing in Brazil

Technological learning in the transfer of knowledge from Malaysia and Switzerland leads to the manufacture of photovoltaic modules in Brazil

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SUMMARY

The installation of photovoltaic module factories in late-industrializing countries depends on the transfer of technical knowledge that, to a large extent, is not contained in manuals and specifications. This article analyzes how this knowledge was transferred and incorporated during the implementation of a photovoltaic module manufacturing line operated by a multinational electronics manufacturing company in Sorocaba, São Paulo state, between 2016 and 2017. The study adopts a single-case design with embedded units of analysis and examines two international learning flows: participation in the ramp-up of a unit of the same company in Johor Bahru, Malaysia, and technical training at the solar simulator manufacturer in Neuchâtel, Switzerland, as well as the internalization of this knowledge in the Brazilian operation. The analysis, based on theories of knowledge transfer in multinational companies, absorptive capacity, and the accumulation of technological capabilities, indicates that the in-person immersion was crucial for acquiring tacit process knowledge, that mastering test metrology required direct contact with the equipment manufacturer, and that codifying the learning into maintenance plans and procedures allowed for its dissemination to local teams. The subsequent implementation of continuous improvement projects, with a 92% reduction in defects associated with lamination parameters, is interpreted as evidence of achieved absorptive capacity.

Keywords: technology transfer; absorptive capacity; technological learning; photovoltaic modules; metrology.

ABSTRACT

Setting up photovoltaic module factories in late-industrializing countries depends on the transfer of technical knowledge that is largely not contained in manuals and specifications. This article analyzes how such knowledge was transferred and incorporated during the start-up of a photovoltaic module production line operated by a multinational electronics manufacturing services company in Sorocaba, São Paulo State, between 2016 and 2017. The study adopts an embedded single case design and examines two international learning flows, participation in the ramp-up of a sister plant in Johor Bahru, Malaysia, and technical training at the solar simulator manufacturer in Neuchâtel, Switzerland, as well as the internalization of this

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knowledge in the Brazilian operation. Grounded in theories of knowledge transfer in multinational firms, absorptive capacity and technological capability accumulation, the analysis indicates that on-site immersion was decisive for acquiring tacit process knowledge, that mastering test metrology required direct contact with the equipment manufacturer, and that codifying what was learned into maintenance plans and procedures allowed it to spread to local teams. The subsequent conduct of continuous improvement projects, with a 92% reduction in defects associated with lamination parameters, is interpreted as evidence of realized absorptive capacity.

Keywords: technology transfer; absorptive capacity; technological learning; photovoltaic modules; metrology.

1 INTRODUCTION

The accelerated expansion of photovoltaic solar energy in the last two decades has been accompanied by due to an equally pronounced geographical concentration of its manufacturing base. According to the According to the International Energy Agency (2022), China's participation exceeds 80% in all stages. major players in panel manufacturing, more than double their share of global demand, And Chinese investment has transformed Southeast Asian countries, such as Malaysia and Vietnam. in relevant exporters of photovoltaic equipment. In this scenario, the installation of Production lines in late-industrializing countries are rarely part of development. autonomous from technology. The most common path is the importation of equipment and processes already established in other units, which transforms the ability to learn from These external sources are a central determinant of the performance of new factories and of Development of local technical skills.

In Brazil, the demand for photovoltaic systems gained momentum following the regulation of micro and mini distributed generation by the National Electric Energy Agency (2012) and, later, within the legal framework established by Law No. 14,300 (Brazil, 2022). The literature on transfer However, technological advancements show that simply installing production capacity does not guarantee the accumulation of technological capabilities. Bell and Pavitt (1993) distinguish the capability of to produce with a given technology, the ability to generate and manage technical changes, and They warn that the second does not automatically follow from the first. This distinction raises a A question that has been little explored in Brazilian empirical studies on the sector is how... Local engineers and teams effectively acquire, assimilate, and utilize the knowledge. Technician who oversees the import of photovoltaic module manufacturing lines.

The aim of this article is to analyze the process of knowledge transfer and internalization. Technician involved in the implementation of a photovoltaic module manufacturing line in Sorocaba, in state of São Paulo, based on two international learning streams, the ramp-up in a

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unit of the same company in Malaysia and technical training at the Swiss manufacturer of
Solar simulators used in the tests. The text is organized into nine sections. After this
The introduction, the second section presents the methodology. Sections three through five build upon the...
reference framework on knowledge transfer in multinational companies, absorptive capacity and
Accumulation of technological capabilities. The sixth section discusses test metrology in manufacturing.
photovoltaics, the seventh analyzes learning flows in Malaysia and Switzerland, the eighth
It examines internalization in Brazil, and the ninth part compiles the conclusions.

2 METHODOLOGY

The research is applied in nature, with a qualitative approach and exploratory objectives.
descriptive. The design adopted was a single case study with units of analysis.
incorporated, a modality that Yin (2018) recommends when the same case contains
subunits whose joint analysis allows for a more complete understanding of the phenomenon.
rather than examining each one in isolation. The issue is the transfer process of
technical knowledge associated with the implementation of a module manufacturing line
photovoltaics, and the incorporated units are the ramp-up in Malaysia, the training in Switzerland and
The internalization of knowledge within the Brazilian unit. The choice of a single case study is justified.
due to its revealing nature, since direct access to the three stages of the process, by the same person
Professionally, it is rarely available to researchers outside the organizations involved.
The empirical context is a multinational electronics manufacturing company operating under contract that,
During the period studied, a photovoltaic module manufacturing line was operating in Sorocaba.
for a manufacturer in the sector. The author worked between December 2016 and November 2017 as
Operations equipment engineer, responsible for deployment, installation and
maintenance of the factory's testing equipment, and participated for approximately two months.
training and ramp-up at the company's facility in Johor Bahru, Malaysia, and a
40-hour technical training at the solar simulator manufacturer in Neuchâtel, Switzerland.
completed with a 100% passing grade on the final assessment. This position allows for the reconstruction of
The journey of knowledge from its external sources to its application in local operations.
Sources of evidence include training records and technical documentation.
equipment, checklists and preventive maintenance plans developed by the author, the
records of scheduled shutdowns and spare parts management, and records of
Completion of continuous improvement projects conducted on the production line. How the author participated.

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Directly from the process studied, the interpretation is subject to hindsight biases and...
involvement. To reduce them, the analysis prioritized documentary records over involvement.
undocumented memories and sought to systematically confront the interpretations with the
literature, a procedure that Eisenhardt (1989) considers essential to increase validity.
The internal and theoretical level of case-based research, both by comparison with studies
convergent as well as through the examination of divergent results.
The analysis was organized based on categories derived from the theoretical framework. For each
The incorporated unit identified the type of knowledge involved, according to the degree of
coding, the transfer mechanisms employed, the barriers observed and the
Learning outcomes. Next, the case activities were associated with the dimensions.
of acquisition, assimilation, transformation and exploration of knowledge as proposed by Zahra and
George (2002). The results should be read as analytical generalization, not statistical generalization.
In the sense proposed by Yin (2018). Out of respect for confidentiality, the company, its clients
Suppliers are not identified by name, and quantitative information is restricted.
if they are formally recorded in the documents analyzed.

3. International Knowledge Transfer in Companies MULTINATIONALS

The literature on international technology transfer has been consolidated since
recognition that technical knowledge is not transferred without cost. Teece (1977), to
Analyzing transfer projects conducted by multinational companies demonstrated that the
The resources consumed to transfer knowledge from one unit to another were substantial.
and varied according to the recipient unit's prior experience and the number of applications.
earlier technological advancements. This finding contradicted the then-widespread view that technology,
Once developed, it could be replicated anywhere at a marginal cost close to
zero. Teece's (1977) contribution was to shift attention from the content of technology to the
The process of its transfer, which came to be understood as a productive activity.
in itself, with costs, deadlines and risks that need to be planned and managed.
Kogut and Zander (1993) further developed this perspective by proposing that the multinational company
It exists, to a large extent, because it is more efficient than the market in transferring
Knowledge that is difficult to codify and teach. For the authors, the more tacit and complex it is, the more difficult it becomes to teach.
The more knowledge there is, the greater the likelihood that it will be transferred internally, between people.

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units of the same organization, and not through licensing or contracts with third parties.
This thesis helps to understand why the implementation of new manufacturing lines in
Multinational companies often involve the transfer of professionals between units.
Knowledge about how to operate, adjust, and maintain a manufacturing process resides in large
part of the people and the routines, and not the documents that describe the product or the
equipment.

Gupta and Govindarajan (2000) investigated the knowledge flows between subsidiaries of
multinational companies identified the value of the stock of knowledge as a determining factor.
originating unit, the motivational disposition of the units involved, the existence and richness
of the transmission channels and the absorptive capacity of the receiving unit. Szulanski (1996), in
A study on the transfer of best practices within companies has reached a conclusion.
which has become an essential reference in the field. Contrary to expectations that the main
The obstacles were of a motivational nature; the author found that the most important barriers...
were linked to knowledge itself, such as causal ambiguity, the difficulty of the relationship
between the parties and, above all, the lack of absorptive capacity of the receptor, a phenomenon that
He termed it internal adherence of knowledge.

Von Hippel (1994) contributed the concept of adherent information, defined as that
whose transfer to another location involves high costs. The author argues that when the
The information needed to solve a problem is distributed across different locations and is
Adherent, the problem-solving activity tends to move to where this information is located, or to
to alternate iteratively between locations. This formulation has direct implications for the
manufacturing. Knowledge about the behavior of a test device, for example,
It is partly concentrated on the manufacturer, who knows the design, and partly on the factory.
The user, who is familiar with the actual operating conditions. Solving technical problems requires,
Therefore, people and information should circulate between these poles, and not just documents.
be sent from one to another.

Argote and Ingram (2000) synthesize these contributions by proposing that knowledge of
organizations are incorporated into reservoirs composed of people, tools, and tasks.
as well as the networks that connect them. Knowledge transfer, from this perspective,
This occurs when there is a change in any of these reservoirs in the receiving unit, and the
The movement of people appears as one of the most effective mechanisms, precisely because
People carry tacit knowledge with them and are able to adapt it to new contexts.
This reference provides the basis for the analysis that follows. The deployment of the photovoltaic line

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The study combined exactly the mechanisms described in the literature, the displacement of a professional for the units of origin of knowledge, their immersion in the routines of these units and subsequent transfer to local teams.

4. Tacit Knowledge, Absorptive Capacity, and Learning ORGANIZATIONAL

The difficulty in transferring technical knowledge relates to the distinction formulated by Polanyi. (1966) between explicit knowledge and tacit knowledge, summarized in the statement that We know more than we are able to say. Tacit knowledge involves skills, Judgments and perceptions that develop through practice and resist full expression. in words, formulas, or procedures. In manufacturing, this type of knowledge manifests itself- whether in the ability to recognize, through the behavior of a piece of equipment or the shape of a measurement curve, which indicates that something is not working as it should, even before any alarm or formal indicator. This knowledge is not absent from the manuals due to negligence on the part of those who created them. He writes. He simply cannot be fully captured in them, which imposes limits on any transfer strategy based solely on documentation.

Nonaka (1994) and Nonaka and Takeuchi (1995) transformed this distinction into a theory. The dynamics of organizational knowledge creation, based on the continuous exchange between tacit and explicit forms. The model describes four modes of conversion, socialization, in that tacit knowledge is shared through coexistence and common experience, the externalization, in which it is articulated in explicit concepts and models, the combination, in explicit knowledge is reorganized and systematized, and internalization, in which the Explicit knowledge is incorporated into practice and becomes tacit again. The relevance of this The model for international transfers lies in showing that the movement of people It promotes socialization, while the development of procedures in the receiving unit... This corresponds to the externalization and combination of what has been learned.

The concept of absorptive capacity, proposed by Cohen and Levinthal (1990), refers to An organization's ability to recognize the value of external knowledge and assimilate it. it and apply it for commercial purposes. The authors argue that this ability depends strongly dependent on related prior knowledge, so that learning accumulates and tends to be dependent on the trajectory. Organizations that do not invest in building a base of Self-knowledge is finding it increasingly difficult to seize opportunities.

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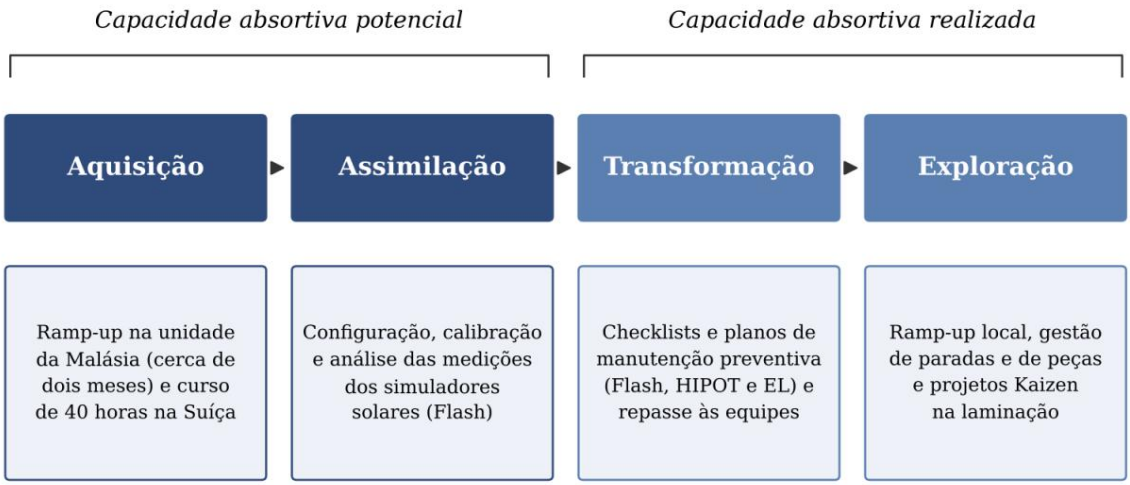
external technologies, because they lack the necessary benchmarks to evaluate them and incorporate them. Kim (1998), in studying the trajectory of Hyundai Motor, added that the Absorptive capacity depends not only on the existing knowledge base, but also on intensity of the effort undertaken, and showed how the deliberate construction of situations of Pressure can accelerate technological learning.

Zahra and George (2002) reformulated the concept by distinguishing four dimensions of capability. Absorptive capacity, grouped into two components. The potential absorptive capacity comprises the acquisition, understood as the ability to identify and obtain relevant external knowledge, and assimilation, which consists of analyzing, interpreting, and understanding this knowledge. Absorptive capacity achieved comprises the transformation, which involves the combination of knowledge acquired through existing knowledge, and exploration, which corresponds to its application in operations, products, or improvements. The authors argue that organizations They may exhibit high levels of potential capacity without converting it into results, which This distinction makes it useful for assessing whether a transfer effort has effectively translated into Operational competence. Figure 1 associates these dimensions with the activities of the case study.

Figure 1 - Dimensions of absorptive capacity associated with the activities of the case study.



Source: compiled by the author based on Zahra and George (2002).

Reading Figure 1 reveals that the international stages of the process focused on dimensions of acquisition and assimilation, whereas the stages developed in Brazil They corresponded to transformation and exploration. This division is not merely chronological. It

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It expresses a necessary condition for the transfer to produce lasting effects, because the Knowledge acquired abroad only translates into a capability of the receiving unit when it is recombined with the local context and applied to operational decisions. Kim (1998) shows, In the case of Hyundai Motor, the learning process has progressed beyond the assimilation of technologies. foreign companies contribute to the development of their own skills as internal efforts increase. It intensified. The case analyzed allows us to examine the first stages of a trajectory. similar within the restricted scope of a production line, where the passage of reproduction The shift from routines to their improvement constitutes the main indicator of learning.

5 Technological Capabilities in Industrializing Economies LATE

The literature on industrial development has made decisive contributions to to understand how companies in late-industrializing countries build competencies based on imported technologies. Lall (1992) proposed a taxonomy of capabilities Technological capabilities at the company level, organized into investment capabilities, related to selection, implementation and commissioning of new facilities, production capacities, related to the operation, maintenance and improvement of processes, and linking capabilities, related to the exchange of knowledge with suppliers, customers, and institutions. For the author, these Capabilities are not automatically acquired by purchasing equipment, but result from... deliberate learning efforts, the intensity of which varies between companies and between countries. depending on the incentives, institutions, and investments in training people.

Bell and Pavitt (1993) further developed this analysis by distinguishing production capacity, understood as the set of equipment, specifications and skills necessary for to operate a technology at a certain level of efficiency, of technological capability, that It involves the resources needed to generate and manage technical changes. The authors argue... that many industrialization experiences rapidly accumulated production capacity without developing, to the same extent, the capacity to modify and improve technologies. acquired. The consequence is prolonged dependence on external sources for anything. a significant change in the processes. This distinction offers a precise analytical criterion for the This case study allows us to ask not only if the Brazilian line has started operating, but also if... The local team developed the conditions to modify and improve the process.

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In the Brazilian context, Figueiredo (2002) examined two steel mills and showed that differences
The trajectories of technological capability accumulation were associated with differences in
the way each company conducted its learning processes, including acquisition
External knowledge acquisition, internal socialization, and the codification of learning. The author
It also demonstrated that these trajectories had measurable effects on performance.
operational, which gives technological learning a concrete economic meaning.
This study is particularly relevant because it shows, in companies operating in Brazil, that the
The external origin of the technology does not, in itself, determine the degree of mastery that the organization possesses.
The recipient will achieve this, with internal learning processes being the differentiating factor.
seemingly similar trajectories.
Ernst and Kim (2002) analyzed global production networks as vehicles for the diffusion of
knowledge for suppliers and local units. According to the authors, companies that
Those who coordinate these networks transfer knowledge to their partners because they need them to.
They meet increasingly higher technical standards, but the utilization of this knowledge depends on...
local absorptive capacity and learning effort of the recipients. Manufacturing
Contract electronics is a characteristic example of this logic, as its units produce
for clients who define stringent specifications and who frequently transfer processes
entire operations were conducted between plants located on different continents. The Sorocaba unit integrated
a network of this nature, which explains both the availability of a reference plant in
Malaysia, regarding the transfer standard adopted.
Brazil's position in the global photovoltaic chain adds a strategic dimension to this.
discussion. The International Energy Agency report (2022) shows that manufacturing outside of
China remains limited and concentrated in a few Southeast Asian countries, whose insertion
was driven by Chinese investments. The expansion of Brazilian demand, stimulated
through the regulation of distributed generation by the National Electric Energy Agency (2012)
and by Law No. 14,300 (Brazil, 2022), it was not accompanied by a manufacturing base.
equivalent. In this context, each experience of implementing manufacturing lines in the country
It also represents an opportunity to develop scarce technical skills, the
The value goes beyond the scope of a single project and reaches the national capacity to operate.
To maintain and improve technologies associated with the energy transition.

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6. Test Metrology in Module Manufacturing

PHOTOVOLTAICS

The manufacturing of crystalline silicon photovoltaic modules generally comprises:
Interconnection of cells in series, assembly of the unit between the front glass and the layer.
subsequent protection, lamination under heat and vacuum for encapsulation, installation of
frame and junction box and final tests. Although the sequence is known, the quality
The product's quality depends on fine process parameters and verifications whose reliability is...
Criticism. Jordan and Kurtz (2013), in compiling approximately two thousand records of degradation of
modules in the field, obtained over approximately forty years, found a rate
median degradation of 0.5% per year. In products whose performance guarantee extends
For decades, undetected defects at the factory can translate into lost production and other problems.
complaints throughout the system's entire lifespan.
The main performance test carried out at the end of the line is the measurement of the characteristic curve.
Current and voltage measurements of the module under artificial lighting, performed in solar simulators.
Pulsed signals, known in the industry as Flash. These devices reproduce, in fractions of
Secondly, a controlled irradiance is used, and parameters are determined from the measured curve.
such as maximum power, short-circuit current, and open-circuit voltage, which define
the commercial classification of each module. The International Electrotechnical Commission (2020),
The IEC 60904-9 standard establishes classification criteria for simulators according to...
spectral correspondence, non-uniformity of irradiance over the test area and the
Temporal instability, characteristics that directly affect the accuracy of the assigned power.
for each unit produced.
In addition to performance testing, the lines undergo electrical safety and integrity tests.
The insulation test, performed on equipment known as HIPOT, verifies whether the
The insulation between the conductive parts and the frame withstands high voltages without failure, as per
the test procedures specified in standard IEC 61215-2 (International Electrotechnical Standard)
(Commission, 2021). Electroluminescence inspection, known by the acronym EL, consists of
Apply a direct polarization to the module and record it with infrared-sensitive cameras.
Next, the radiation emitted by the cells. Fuyuki et al. (2005) demonstrated that the intensity
This emission is related to the diffusion length of minority carriers, which
This made the technique an effective tool for revealing microcracks, inactive areas, and other...
Flaws invisible to conventional visual inspection.

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The importance of these tests is reinforced by the survey conducted by Köntges et al. (2014), carried out within the framework of a cooperation program of the International Energy Agency, which systematized the failure modes of photovoltaic modules observed in the field, such as microcracks in Cells, discoloration and delamination of the encapsulant, and failures in interconnections. Part of these The methods originate from manufacturing defects that could be detected by testing. suitable at the end of the line. This gives the test equipment a function that goes beyond Conventional quality control. They constitute the main source of information about the The behavior of the process, and the data it produces, informs adjustment decisions at various stages. previous processes, such as cell interconnection and lamination, make it more reliable. a condition for the improvement of the process itself.

This informational function is only performed if the measurements are reliable, which refers to Fundamentals of metrology. The International Vocabulary of Metrology, published by the Joint The Committee for Guides in Metrology (2012) defines metrological traceability as... property of a measurement result that can be related to a reference by means of from an uninterrupted and documented chain of calibrations, each contributing to the Measurement uncertainty. The guide to the expression of measurement uncertainty, from the same committee (Joint (Committee for Guides in Metrology, 2008), establishes the procedures for evaluating and To combine the uncertainty components. In a photovoltaic line, the simulator calibration. solar panels with reference modules and periodic verification of their condition are therefore the The link that connects the stated power of each product to recognized standards. internationally.

7. LEARNING FLOWS IN MALAYSIA AND SWITZERLAND

The first incorporated unit of the case was participation, for approximately two years, in the training and ramp-up of a unit of the same company in Johor Bahru, Malaysia, focusing on the manufacturing processes of photovoltaic modules, maintenance and configuration and deployment of test equipment. Ferdows (1997), when analyzing the role The strategic analysis of factories abroad showed that units initially designed for Producing at low cost can evolve into higher-level functions, in which they then contribute... with knowledge for the network. The Malaysian unit acted, in this case, as a source of knowledge for the Brazilian plant. In a later study, Ferdows (2006) argues that the Production knowledge changes continuously, and the transfer mechanism must be...

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chosen according to the degree of codification of that knowledge and the speed at which it is acquired.
It changes.

The value of the experience in Malaysia stemmed primarily from participating in a real ramp-up, and not in a simulated environment. Terwiesch and Bohn (2001) show that the ramp-up period It involves intense process learning, but also a tension between utilizing the capacity to produce and use it to experiment and understand the process. Pisano (1996) distinguishes learning prior to production, obtained in the laboratory or on a pilot scale, from learning by doing, which takes place on the plant itself, and shows that the latter is indispensable when available scientific knowledge does not allow for prediction Behavior of the process on an industrial scale. Equipment startup in a The operational line exposed the author to real-life situations of adjustment, failure, and correction that These behaviors would be difficult to replicate in the classroom, which corresponds to the mode of socialization. described by Nonaka (1994).

The literature on learning curves helps to gauge the economic value of this type. from experience. Wright (1936) observed, in the aeronautical industry, that the cost of labor per unit decreased at an approximately constant rate with each doubling of production. accumulated. Argote and Epple (1990) showed that this phenomenon manifests itself in various sectors, where learning rates vary considerably between organizations and that part The acquired knowledge can be transferred between plants, but it can also depreciate. over time. Participation in the ramp-up of a plant that had already covered part of Its learning curve allowed the Brazilian unit to benefit from experience. accumulated elsewhere, which, according to these authors, is equivalent to starting the curve itself. at a more advanced level.

The second incorporated unit was the 40-hour technical training at the manufacturer's facility. Solar simulators in Neuchâtel, Switzerland, focused on installation, maintenance, configuration, calibration and analysis of measurement results from Flash equipment, completed with 100% success rate in the final evaluation. The choice of the manufacturer as a source of This knowledge is consistent with Von Hippel's (1994) argument about adherent information. Knowledge of the operating principles, operating limits, and Calibration procedures for a solar simulator are focused on whoever designed it, and the The most efficient way to access it is through direct contact with that source. The training topics correspond precisely to the metrological elements discussed in the previous section, whose Understanding is essential for the reliability of production data.

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The effectiveness of training, however, is not measured solely by performance on assessments.
Finally, Kirkpatrick and Kirkpatrick (2006) propose four levels of evaluation, the reaction of
participants, learning, behavioral change at work, and outcomes for the
organization, and they warn that the last two are the most relevant and the most difficult to
Check. Baldwin and Ford (1988), in a review on training transfer, show that
The application of what has been learned depends on the characteristics of the participant and the design of the...
training and the work environment, and the maintenance of learning over time.
requires effective application opportunities. The analysis of learning flows in Malaysia and
In Switzerland, therefore, it is only complete with an examination of what has been done with this knowledge in...
Brazilian unit, the subject of the following section.

8. The Internalization of Knowledge in the Brazilian Unit

Back in Brazil, the author assumed responsibility for the implementation, installation, and
maintenance of the testing equipment at the Sorocaba factory and the initialization of these
equipment in the local ramp-up. The first evidence of knowledge transformation was the
Preparation of preventive maintenance checklists for Flash, HIPOT, and EL equipment.
with defined frequencies and verification items related to safety, engines, and
belts and calibrations. This work corresponds to what Nonaka and Takeuchi (1995)
They describe it as externalization and combination, since it converted the documents into structured documents.
knowledge acquired in Malaysia and Switzerland, combining it with information from textbooks.
from the manufacturers and with the specific conditions of the Brazilian production line. The checklists became,
Thus, the main vehicle for disseminating this knowledge beyond the trained professional.
Maintenance management broadened the scope of this transformation. The author then took over managing the plan.
maintenance, scheduling line shutdowns, monitoring the technical team, and managing
the inventory and life cycle of spare parts. Nakajima (1988), when formulating maintenance
total productive capacity showed that the overall efficiency of equipment depends on reducing
simultaneous reduction of losses due to downtime, speed, and defects, and that this reduction requires...
Participation of the operation and maintenance teams. In the case of test equipment, the
Maintenance takes on an additional dimension, since the equipment is available, but
Miscalibrated, it continues to produce data, but misleading data. The integration between the
Metrological knowledge acquired in Switzerland and the maintenance routine therefore constituted
a central element in the transformation of knowledge.

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The transfer of knowledge to the technical and operational teams represented the moment when the knowledge was...
It ceased to belong to an individual and became part of the organization's routines. Argote and
Epple (1990) warns that organizational knowledge can depreciate when it depends on
Few people use it, and it is not incorporated into shared procedures, tools, and practices.
Argote and Ingram (2000) add that the transfer is only complete when it causes
Changes in the knowledge reservoirs of the receiving unit. The combination of
structured documentation, team training and monitoring of project implementation
The activities aimed precisely to reduce this risk by distributing knowledge among people.
procedures and tools, so that the operation of the line did not depend exclusively
due to the presence of the professional who had participated in the international training.
The clearest evidence of absorptive capacity achieved, in the sense of Zahra and George (2002),
This came with leading continuous improvement projects within the production line itself. The author participated in
eleven Kaizen projects in the company, focused on reducing waste, increasing yield, and...
reduction of defects in rolling mills and reduction of downtime, and acted as co-leader of a project.
dedicated to reducing defects in the rolling process associated with recipe parameters
of the equipment. Conducted by a team comprised of Production, Quality, and Engineering.
Based on the PDCA cycle, the project recorded a 1% increase in yield.
92% reduction in recipe-related defects, 30% increase in productivity and
estimated annual savings of approximately US$437,000, according to records from
closing.

These results are significant in light of the distinction made by Bell and Pavitt (1993). The operation of
an imported line, with equipment installed and maintained according to the standards received,
This corresponds to production capacity. Modifying the parameters of a critical process,
based on the analysis of data generated by test equipment whose reliability was
Secured locally, it corresponds to an initial form of technological capability, still
restricted to incremental improvement, but qualitatively distinct from mere reproduction of
routines. The observed trajectory is consistent with Figueiredo's (2002) evidence that the
Internal learning processes, and not just the external origin of the technology, determine
the degree of mastery achieved by the receiving organization, and how that mastery translates into
Measurable operational gains.

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CONCLUSION

This article analyzed the process of transfer and internalization of technical knowledge in implementation of a photovoltaic module manufacturing line in Sorocaba, based on two international learning flows, ramping up within a unit of the same company in Malaysia and technical training at the Swiss manufacturer of solar simulators. The analysis, supported in theories of knowledge transfer, absorptive capacity and accumulation of technological capabilities allowed us to identify what the process taught us about the formation of local competencies.

The first lesson is that process knowledge is most valuable for the implementation of a Photovoltaic technology is predominantly tacit and can only be acquired through immersion in... real-world operations. Participation in the ramp-up of the Malaysian unit exposed the professional to situations adjustments, failures, and corrections that no manual could fully describe, confirming the propositions by Polanyi (1966), Kogut and Zander (1993) and Argote and Ingram (2000) on the role of the people involved in the transfer. The documentation received was helpful, but only as a supplement. from the experience gained in the production environment.

The second lesson refers to metrology. The domain of configuration, calibration, and analysis. The measurements from the solar simulators required direct access to the equipment manufacturer, where This knowledge was concentrated. This learning proved indispensable because... The reliability of the test data greatly influences the commercial rating of the modules. Regarding the ability to identify and correct problems in the earlier stages of the process. productive. In other words, metrology has ceased to be treated as a support activity and It came to be recognized as the basis for procedural decisions.

The third lesson concerns coding. Checklists and preventive maintenance plans. Developed at the Brazilian unit, they converted the knowledge acquired abroad into instruments that could be shared, taught, and audited. Without this step of Transformation, knowledge would remain restricted to the trained professional and would be subject to change. to the depreciation indicated by Argote and Epple (1990), with a permanent risk of loss in cases of turnover. Coding, therefore, was what allowed individual learning to occur. would translate into organizational capability.

The fourth lesson is that the most consistent measure of a transfer's success is not the departure date. of the line, but in the subsequent ability to improve it. A 92% reduction in associated defects. to the lamination parameters, obtained by a local team based on data produced by

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Equipment maintained and calibrated locally indicates the transition to production capacity.
for an initial form of technological capability, in the terms of Bell and Pavitt (1993). This refers to
This represents an incremental improvement, but one that distinguishes a team that merely replicates routines.
received from another capable of improving them.

The study has limitations that should be considered. It is a unique case,
analyzed retrospectively by a professional who participated in the process, which requires
Caution is advised regarding interpretation biases, even though the analysis prioritized records.
documentary. Furthermore, the levels of change were not formally assessed.
behavior and training outcomes, in the terms of Kirkpatrick and Kirkpatrick
(2006), and the findings constitute analytical generalizations, not statistical ones. Studies with
Other plants and other periods would be needed to verify the regularity of the patterns.
observed here.

From a practical standpoint, the results suggest that companies and policymakers
Those interested in expanding the photovoltaic manufacturing base in Brazil should address the training...
People are a central component of any deployment project. Immersion in plants.
For reference, contact with manufacturers of critical equipment and the requirement for coding.
The transfer of acquired knowledge is a relatively low-cost, high-impact mechanism.
Regarding the technical autonomy of local units.

As a research agenda, it is recommended to conduct multiple case studies that
comparing different photovoltaic plants installed in the country, the longitudinal evaluation of
retention of transferred knowledge after the departure of professionals trained abroad and the
investigation of the role of universities and technical training centers in the construction of
prior absorptive capacity. These studies could clarify under what conditions experiences
One-off transfers translate into lasting technological capabilities for the sector.

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