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Analyzing the Role of Human Capital in Strengthening National Innovation System through University-Industry Research Collaboration: A TRIZ-Based Approach

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Abstract. University-industry research collaboration (UIRC) is seen as a key measure in formulating national-level indicators of research and innovations and economic growth. Despite the extensive availability of shreds of evidence indicating the importance of such areas of collaboration in developed and developing countries, existing literature on the strengthening of the National innovation system (NIS) via UIRC is still scarce. Literature has highlighted the impact of human capacity as having a strong influence on researchers' innovative activities as well as on the NIS. Moreover, in strengthening the NIS, it is considered mandatory to model human capacity, specifically, in the aspects of universities- industries personnel. In this paper, we explore the usage of the TRIZ thinking models together with the adaptation of its toolkit to shed insights on the influence of human capacity on NIS. Using the TRIZ heuristic modeling paradigm, a systems model of human capacity and its significant influence on NIS has been demonstrated. Thus, the findings of this research suggest the tremendous potential of employing TRIZ as a systems modeling tool for explorative analysis of intangible outcomes. The potential of using TRIZ as an explanation module for systems thinking will be a game-changer for knowledge-based modeling of national innovation systems.

Keywords: University-Industry Research Collaboration, National Innovation System, Human capital, Theory of inventive problem solving (TRIZ) approach.

1. Introduction

It is usually accepted that technological change and innovation are key requirements to ensure sustained economic growth. Specifically, to overcome the economic crisis and for winning the future, all countries need to boost their capacity to strengthen the national innovation system. Moreover, many studies provide pieces of evidence for the strategic importance of the University-Industry research collaboration that is producing a very huge impact on the national innovation system [1-7]. Regardless of extensive

indicators of the significance of UIRC, the rate of technological innovation from UIRC is seen to be not satisfactory in several developing countries [8-10]. Several studies were conducted to explore the factors that can enhance such rates of technological innovation through efforts in minimizing the barriers of UIRC. Nevertheless, most works focused on university-industry orientation factors which include: conducting workshops & seminars and hiring educated, trained and skilled personnel, which usually act as a symptomatic way out of the problem [11-15].

Furthermore, universities and industries are seen as the primary components of the national innovation system (NIS) which directly perform technological innovation [16-18]. In this regard, the authors [2] have emphasized that if the aim is to strengthen NIS, it is advisable to investigate the influence of UIRC on NIS. However, comprehensive literature about the factors relating to the UIRC and their influences on NIS is still scarce.

Secondly, the main limitation as highlighted in current literature is the lack of a systemic approach, which has led to the limited predictability of outcomes [19-20]. Moreover, NIS maintain their existence through the mutual interaction of their primary parts (“Universities and industries”) that demand a systemic approach for its evaluation [21-22]. Thus, a systemic approach will be required to overcome fundamental weaknesses in consequential mapping owing to the reliance on its linear model [23].

This study, therefore, aims to investigate the influence of UIRC on the NIS.

In addition, this study proposes the usage of the TRIZ model of systems thinking and key instruments from its toolkit. The theory of Inventive Problem Solving or TRIZ provides a collection of visual thinking instruments that takes a two-stage approach and thereby helps in systematically resolving complex problems [24, 25]. The realization that the presence of a contradiction that is worth to be identified, represented, and solved algorithmically, serves as a powerful problem-solving toolkit [26]. In this research, we have explored preliminary TRIZ instruments, the Cause and Effect Chain Analysis (CECA), Function Modelling, and Contradictory Analysis, to provide insights into the complexities of modeling abstract relationships. The use of the TRIZ instruments that have been formulated by its founder Genric Altshuller as elements of productive thinking in innovative engineering is evaluated as a bridging method in addressing the concerns addressed in these papers [27-29].

For example, the use of CECA not only identifies the root causes of the problem but also provides the pathway to the optimum solution. Thus, by utilizing TRIZ instruments as a series of problem formulation and guided solutions outlining pathways, an enriched perspective has been presented.

The paper is structured as follows, section 2 briefly discussed literature review and hypothesis development, and detailed methodology is illustrated in section 3. Section 4 provides results and analysis of the study followed by a conclusion and recommendations in section 5.

2. Literature Review and Hypothesis Development

It is generally accepted that human capital (HC) is an essential part of any national innovation system and a central element of economic growth theory. An innovation system and economy with a larger total stock of human capital experience faster growth [30]. However, it is observed that when UIRC is formed, imbalanced personnel in universities and industries is one of the major constraints between them. Imbalanced personnel here refers to the inequality in education and skills, exchange of knowledge, expertise, and the bits of advice among the research organizations to resolve the issues and problems that arise during such research and innovation processes [31]. Similarly, authors of [32], identified that highly educated and trained personnel are able to highly contribute to the development of research and innovations. It is observed that when university-industry research collaboration is formed, HC is one of the major constraints between them [33].

On the other side, the majority of firms that collaborate with universities to recruit personnel who can fulfil the needs of the industries. Universities in developing countries focus on their curriculum to produce graduates who are able to meet the needs of the industry [34]. Furthermore, the authors of [35], defined that education and training institutions must have a research-based curriculum rather than a theory-based one. Theoretical knowledge is insufficient for producing capable human capital and the development of research and innovations which is also the major bottleneck hindering the innovative interactions between universities and industries. Human capital in universities and industries is embodied in skilled and experienced personnel who provide professional training and skills via exchanging of information and expertise with each other and increase the levels of technological abilities, which lead to the R&D partners' satisfaction and performance and eventually NIS performance [36-41].

The literature describes knowledge transfer of best practices from developed countries as workable solutions for mapping to apparently similar conditions in local contexts. However, such over-generalised outside-in prescribed solutions tends to be a misfit at times. For example, the overall standard of education and training system in developing countries needs to be carefully treated in an attempt to produce the required human capital to strengthen the NIS. In addition, not taking a systems approach is the key disadvantage, whereby a black-box method is taken, with non-connected constructs tends to be proposed in isolation. In addition, methods that can fully map the current state of the knowledge base are required to enable a visual depiction of components of a National Innovation Systems modeling.

3. Methodology

In this study, TRIZ models and instruments have been utilized to depict the high-level macro systems. A functional analysis was firstly used to reverse engineer the knowledge flows based on the review of the literature and the past research as carried out by the team of researchers [5-6, 14, 17]. Subsequently, a Functional model was formulated, followed by the Cause and Effect Chain Analysis and Engineering contradiction modelling. In this preliminary works that we have undertaken, an elaborate TRIZ-based Engineering systems model has not been formulated. Future works will address such an extension where flows models of TRIZ will be taken into consideration. Section 4 then illustrates the more comprehensive view of the national innovation model with a discussion on what can the use of TRIZ provide.

3.1 Reverse Engineering System Model

In figure 1, the function model is showing a smooth way of strengthening the NIS. The function model provides a systematic approach to generating an inventive solution to the problem. The constructs are based on our past quantitative models. Figure 1 represents the annotated functional flows that have been explicitly stated as a function name.

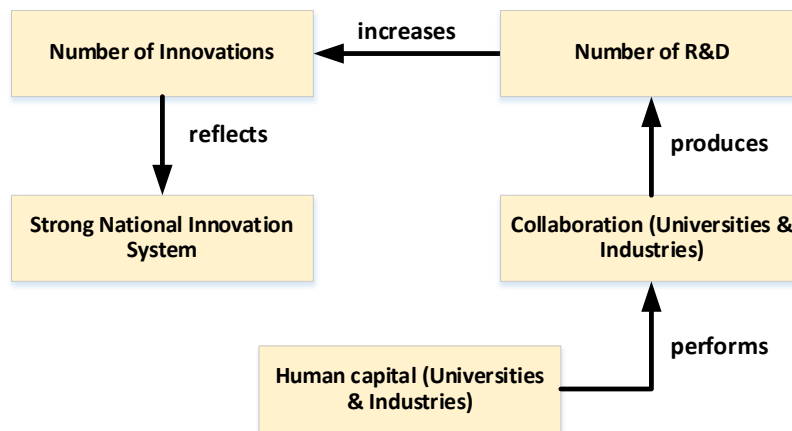


Fig 1: Functional Model Depicting the Current State of UIC as an enabler for a strong NIS

This step has been instrumental to highlight the use of visual modelling as a way of augmenting tacit knowledge as extracted from past system thinking models. The functional modelling tools has presented a way of adopting a knowledge-based approach to characterize and depict the knowledge flows and interactions.

3.2 Functional Analysis

Based on the reverse engineering stage in providing a deeper understanding of the system thinking models, we present a function model describing the generic structure of systems thinking instruments. We have identified the main useful function as a system approach in informing policymakers and in the simulation of the knowledge-based economy. The detailed functional model with their influences is illustrated in figure 2

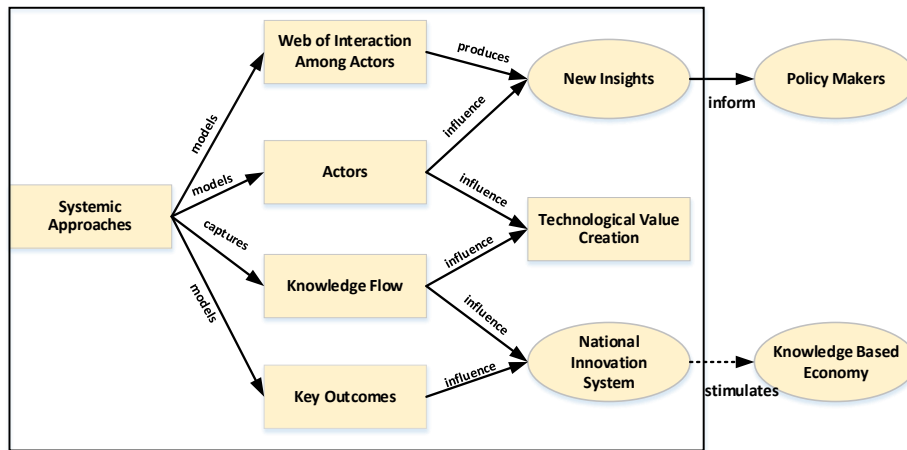


Fig 2: Understanding of Systems Relationship

We have further defined a meta-level function model that describes a need for the TRIZ-based visual knowledge system as shown in figure 3

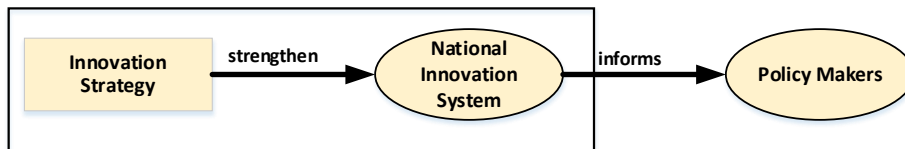


Fig 3: TRIZ-based Explainable Systems Model

3.3 Cause and Effect Chain Analysis

In adopting the Cause and Effect method for the problem modelling of strengthening National Innovation systems, a collaborative brainstorming approach was used. The structuring of the Cause and Effect chain analysis is maintained, while a multi-disciplinary team is engaged. The method used is outlined as follows:

1. We start the session with the formulation of the goal of the system. The goal of this CECA activity has been to strengthen the NIS

2. The second step has been the definition of target disadvantage to serve as the starting node in the cause and effect chain. In our situation, this was defined as “Weak NIS” as the target to be addressed.
3. We then proceeded with an iterative questioning as to why this happens. There are hypotheses established, which are then verified by either a literature review or a consultation with relevant experts
4. The brainstorming element in this process is key as the various modelling possibilities are evaluated and a coherent flow is accepted
5. The process goes on until a key disadvantage is identified. The involvement of decision-makers and policymakers adds value to this stage as the process itself becomes co-created with stakeholders.

The CECA model in Figure 4 is showing some challenges to the function model that universities and industries specifically in developing countries always face the challenge of low-quality of human capital, and the reason behind this is the quality of education that is not up to the standard of developed countries. However, changes in the index of education can provide a well-educated workforce to the universities and industries. Nevertheless, after nurturing an educated workforce in the country, developing countries normally face the challenges of a brain drain that not only affects the NIS but also deteriorates the economic condition of the country. Upon an iterative refinement, specific programs were then outlined, and additional insights were gained.

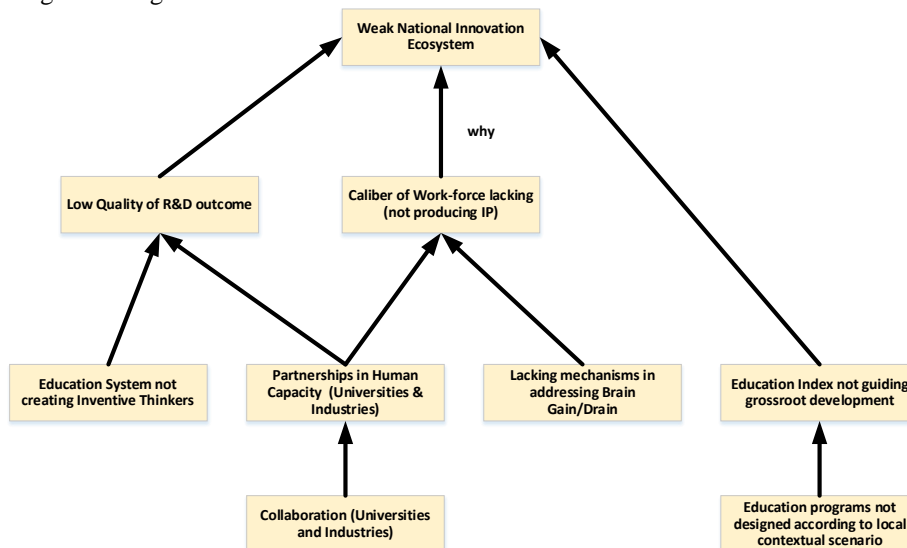


Fig 4. Cause and Effect Chain Analysis

3.4 Engineering Contradiction Model

Subsequently, an Engineering Contradiction model was formulated for the macro-level problem at hand for strengthening the NIS. The preliminary outcomes and the potential of using the tool will be evaluated. Based on the models that have been produced it is seen that both micro and microlevel heuristic models can be built. In engaging experts in systems modelling, policymakers, and TRIZ thinkers, it was possible to construct alternative models as opposed to the state-of-the-art reliance on black-box models.

IF :	Standard Initiatives are targeting the increase of the Quality of primary education
THEN :	Universities and industries will have access to qualified (human capacity) expertise
BUT :	Brain drain becomes a major concern

Program-level model micro encoding that defines the current approach to dealing with NIH modeling

IF :	Standard Initiatives are targeting in increasing the Quality of primary education
THEN :	A competent Workforce will be nurtured
BUT :	Participatory and Access gaps for grooming local leaders/champions still not addressed

Contradiction Analysis. Based on the improving and worsening parameters, we obtained the suggested inventive principles from the contradiction matrix. For the domain of strengthening the NIS, it was necessary to map the substances of a typical technical system to human dimensions of increase in human capacity quality and brain drain indicators respectively.

The inventive principles were formulated through an extensive study of the innovative solution from past patents. These inventive principles give an insight into the potential approach that can be utilized to solve a challenge. Table 1 shows the inventive principles for improving and worsening parameters.

Table 1. Remodeling Solutions based on Inventive Principles

Recommended Inventive Principles	Inventive Trigger as a guideline	Potential solutions from the suggested inventive principles.
# 6 Universality	Make an object perform multiple functions	Creating avenues for professionals/thought leaders by diversifying their roles
# 3 Local quality	Make an object suitable for every condition.	Create a conducive environment with sufficient support for systematic brain gain programs (goal-driven) and averting brain drain.

# 10 Prior Action	Perform the required change in advance	Create support systems in advance to make it favorable for brain gain/brain drain
#24 Mediator	Perform as an Intermediary	Establish an intermediary agency as a UIC to reverse the outflow of talent

3.5 TRIZ based Framework for Explorative System thinking

Based on the worsening (loss of substance) and improving parameters (amount of substance) from the TRIZ contradiction matrix, table 2 shows 4 inventive principles {(#3 local quality, #6 universality, #10 prior action, and # 24 Mediator)}.

Table 2. Summary of the Solution

TRIZ Tool	Proposed solution
1 Function Model	Input: Human capital in universities and industries Output: Strong NIS
2 Cause and Effect Chain Analysis	Low quality of human capital in universities and industries
2 Engineering Contradictions Challenge 1 Root causes: Solutions: # 3 Local Quality #10 Prior Action	Standard of Education Changes in the index of Education
Challenge 2 Root cause Solutions: #6 Universality #24 Mediator	Loss of human capital Brain Drain Number of local employment

Figure 5 shows two parameters “standard of education and brain drain” as the constraints, concurrently, outlining parameters “index of education and number of employees” as the suggested solution to diminish the constraints and to enhance the innovative capabilities of HC in universities and industries and consequently strengthen the NIS. Based on the developed framework, this model further incorporates from relationships from previous literature that human capital not only improves the technological competencies of universities and industries but also strengthens the NIS by improving the quality of R&D and the number of innovations. Thus, from the findings of this research the TRIZ-based framework has concluded that human capacity is the key factor to enhance the outcome of NIS.

TRIZ’s approach consequently provides the solution to diminish the constraints by indicating the factors of educated and skilled personnel (ESP) as the critical factors of UIRC. An extensive and exhaustive discussion is elaborated in section 2.

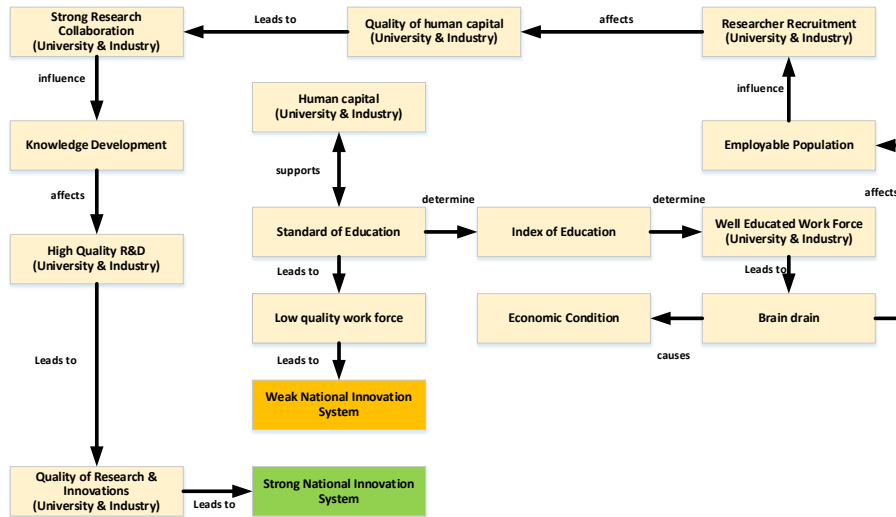


Fig 5. TRIZ-based framework to strengthen the NIS

4. Conclusion and Future Direction

In transferring best practices by adopting an outside-in approach and employing indicators from de-contextualized scenarios, intrinsic aspects of local system conditions tend to be overlooked. As opposed to using a specialised set of parameters for the domain of Human Resource [42], this research has adopted the original parameters of Alshuller which we used as triggers for suggesting human capacity related indicators. Our goal was to explore the TRIZ-based methods in themselves as a means of augmenting and enriching the systems modelling ability. The role of TRIZ as a means of knowledge representation whereby a heuristic modelling of knowledge flows was then visualised. Our paper has demonstrated TRIZ models as a way to bridge the gap between research and innovation organizations and policymakers by illustrating the influence of HC on NIS. The TRIZ approach has helped policymakers to see the root causes of the problem and the ways to overcome it [43,44].

As opposed to taking an entirely black-box model, TRIZ practitioners, consider an analytical approach where human capacity aspects are structured as components or even as building blocks in the formulation of a national-scale innovation system. We find that when an empirical study is adopted there is a tendency to specialize the study to a geographical region, with the main difficulty in repurposing the models constructed. While these studies highlight complexities of context, we have explored the capacity of TRIZ in augmenting these abstract systems thinking models with a representation of intrinsic concepts within an analytical supportive framework.

Reverse Engineering and visualization as function models has been a crucial component of the proposed methodology to systematically augment black-box models. CECA is then adapted to suit the design of the framework for an explainable systems model that drills down into the knowledge-flows and interaction pathways. The use of engineering contradictions as a means to identify knowledge gaps provided support in externalizing the knowledge locked up in black-box system models. The technical parameters however needed to be customized and mapped as social parameters. This paper has shown that TRIZ-based methods can be adapted and repurposed to serve as social systems modelling tools.

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