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# Interdisciplinary Advances in Technology, Engineering, and Applied Sciences

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**ABSTRACT**

This study used a mixed-methods, multi-disciplinary research design to investigate the role that interdisciplinary collaboration between technology, engineering and applied science played in innovation and problem-solving. The participants included 185 engineering, computer science, information technology, environmental studies, biotechnology and other applied science professionals and researchers identified through purposive sampling based on prior interdisciplinary projects or research experience. A structured questionnaire was used to gather quantitative data on the dimensions of interdisciplinary collaboration, knowledge integration, technological capability, research collaboration, innovation performance and real-world problem-solving capacity, with a sub-sample of 18 interviewees following this with semi-structured interviews to elicit information on how knowledge was being shared and integrated across disciplines. Descriptive statistics, Pearson correlation, and multiple regression were used to analyse the quantitative data, and Braun and Clarke's thematic analysis framework was used to analyse the data from the qualitative interviews, with the results from the two strands then combined. The quantitative findings revealed that innovation performance and problem-solving ability were positively and significantly related to interdisciplinary collaboration, knowledge integration, technological capability, and research collaboration, with interdisciplinary collaboration, and knowledge integration having the highest beta coefficient values in the regression model. Structured collaborative platforms, boundary spanning communication practices, shared conceptual frameworks, trust-based relationship building, and institutional support structures were identified as the five recurring mechanisms that support cross-disciplinary knowledge sharing identified through thematic analysis of the interview data. Analysis of quantitative and qualitative results showed that the structural opportunities for interdisciplinary collaboration need to be supported by the relational and cognitive integration mechanisms that enable interdisciplinary engagement to lead to outcomes of innovation and applied problem solving. The results show the importance of intentional multi-disciplinary design and support systems in driving technology, engineering and applied-science innovation.

**Keywords:** interdisciplinary collaboration, knowledge integration, technological innovation, applied sciences, mixed-methods research, thematic analysis, problem-solving capacity.

## INTRODUCTION

The Nature of Technology, Engineering, and Applied Sciences (TEAS), as a field that is increasingly interdisciplinary – including both technology and engineering, as well as applied sciences – is faced with growing challenges, from climate change to the design of intelligent systems, that are too complex to be solved by a single discipline alone and increasingly demand the expertise of multiple disciplines working together (National Academies of Sciences, Engineering, and Medicine, 2005). Interdisciplinary research is a field that draws upon ideas, methods and data from various disciplines to generate insights and solutions that could not be obtained by research in one discipline alone (Klein, 2010; Repko & Szostak, 2020).

There is a large amount of evidence out there that interdisciplinary collaboration is associated with improving innovation performance, because the re-combination of different knowledge bases is recognized as one of the main drivers of the emergence of new technological solutions (Wagner et al., 2011; Leahey et al. 2017). The field of team science literature has also shown that co-located, interdisciplinary teams have been shown to produce more novel, and practically useful, solutions to complex problems than are single-discipline teams (Stokols et al., 2008; Hall et al., 2018).

While there is a strong argument that interdisciplinary collaboration provides benefits, these benefits are not automatic, but rather are tied to how well knowledge from across different disciplines is truly integrated, as opposed to simply juxtaposed (Bammer, 2013; MacLeod, 2018). Knowledge integration often means establishing shared conceptual frameworks, common lexicon, and understanding of different disciplinary understandings and processes, which can be challenging and demanding (Pennington, 2008; Siedlok & Hibbert, 2014).

Another key enabling factor of interdisciplinary innovation concerns technological capability and the presence of structured research collaboration mechanisms, which enable knowledge exchange across disciplines within the infrastructure and organization of its collaborative process (Cummings & Kiesler, 2005; Salazar et al., 2012). More than four decades ago, interdisciplinary research has gained in popularity and impact on citations (Van Noorden 2015), but has also been hampered by existing and ongoing challenges, like institutional reward systems and communication barriers between disciplines, that are limiting its potential for innovation.

While there are also significant numbers of studies examining the relationship between interdisciplinary collaboration and innovation or problem-solving outcomes, few have simultaneously attempted to quantify the relationship and explore the qualitative mechanism(s) by which cross-disciplinary knowledge is shared in contexts related to technology, engineering and applied-sciences (Bridle et al., 2013; Fiore, 2008). To build effective and evidence-based interdisciplinary collaboration strategies in applied research and practice, it is important to integrate these complementary strands of evidence (Gray, 2008). Therefore, the present study employed a mixed-methods design to explore the relationships between interdisciplinary collaboration, knowledge integration, technological capability, research collaboration and innovation performance and real-world problem-solving capacity and to elucidate the mechanisms underlying effective interdisciplinary knowledge sharing (Lyall et al., 2011).

## LITERATURE REVIEW

In the last 20 years, the conceptual underpinning of interdisciplinary research has been much theorized. The degree to which disciplines are integrated across different disciplines has led to an influential taxonomy by Klein (2010) which differentiates multidisciplinary, interdisciplinary, and transdisciplinary modes of collaboration as adopted by much of the interdisciplinarity literature. Similarly, Choi and Pak (2006) provided some understanding of the definitional differences between the modes in the health and applied research settings, pointing out that it is crucial for the mode to be an integrated one, not merely the juxtaposition of different disciplinary experts, if new problem-solving power is to be created. Repko and Szostak (2020) defined a systematic process model for interdisciplinary research, and concluded that the structured integration techniques increased the coherence and applicability of interdisciplinary research products over the unstructured collaborative ones.

Past empirical studies on the link between interdisciplinary collaboration and innovation outcomes have yielded mixed yet broadly similar results. Wagner et al., (2011) reviewed methods of measuring interdisciplinary research and found that articles with broader knowledge bases were more likely to have impact and be innovative but that the effect was moderated by the extent to which the knowledge was truly integrated. In an interdisciplinary scientist productivity and prominence study, Leahey et al., (2017) found that interdisciplinary scientists were more likely to be "prominent" but were less likely to be "productive" in some instances, signifying an enduring "innovation-efficiency" tradeoff. In line with its acknowledged importance as a way to create new scientific and technological knowledge, van Noorden (2015) was able to document bibliometric data indicating that interdisciplinary research had increased significantly in volume and average citation impact.

The science of team science research has made a significant impact on the knowledge about how the collaborative team structures influence the interdisciplinary innovation outcomes. A foundation was laid for further empirical studies by Stokols et al. (2008) who founded the science of team science as a new science that explores the antecedents, processes, and outcomes of collaborative scientific research. A thorough review of empirical studies in this area by Hall et al., (2018), found that the collaborative research results were consistently related to team diversity, quality of communication and shared mental models. In studying interdisciplinary collaboration, Fiore (2008) argued that the most productive way to view it is as a team effort, and that principles from the team cognition research could significantly enhance the design of interdisciplinary research efforts. In studying collaborative research with researchers from different disciplines and organisations, Cummings and Kiesler (2005)

discovered that there existed very meaningful differences in the difficulties in coordinating geographically and discipline dispersed teams, highlighting the need for purposeful infrastructure for collaborative research.
Knowledge integration has been consistently found as a key process that connects interdisciplinary cooperation to innovation performance. Focusing on the processes of cross-disciplinary collaboration and learning, Pennington (2008) found that shared conceptual frameworks were necessary to make the diverse knowledge of the disciplines useful and integrated. Bammer (2013) proposed a framework of integration and implementation sciences specifically designed to help systematically integrate disciplinary knowledge to solve problems in the real world, and Salazar et al. (2012) found an empirical link between the capacity for integrative solutions – which was defined as the ability of a team to combine multiple pieces of knowledge into a coherent solution – and innovation performance across a variety of science teams. However, MacLeod (2018) warned that domain specificity in disciplinary knowledge and methods can result in significant practical challenges for integration which are mediated by ongoing relational and cognitive efforts.
The interdependence of organisation and institutions in the context of interdisciplinary collaboration has also been the subject of continuous research efforts. Siedlok and Hibbert (2014) examined how interdisciplinary research is organized and found that funding structures, physical co-location and leadership support are important enabling factors, and that disciplinary status hierarchies and misaligned incentives are major impediments that do not seem to have changed. In a specific focus on collaborative leadership, Gray (2008) found that collaborative leaders who were highly active in fostering trust and communicating across boundaries had significantly more positive collaborative results. Bridle, et al., (2013) polled early-career researchers about support structures for interdisciplinary research, and identified institutional provisions, such as mentorship and specific interdisciplinary training courses, as significant determinants of the confidence and effectiveness of those doing interdisciplinary research.
The methodological perspective, on the other hand, is becoming more popular for capturing both the measurable outcomes and underlying mechanisms of interdisciplinary collaboration, and it is here that the mixed-methods approaches have gained in popularity. Creswell and Plano Clark (2018) suggested that a mixed method approach is ideal for the researcher to both draw statistical connections and to provide rich description of the processes that underlie the connections, especially in regards to complex organizational phenomena like interdisciplinary collaboration. Similarly, Tashakkori and Teddlie (2010) highlighted those mixed methods designs allow for triangulation and for the better understanding of multidimensional constructs than quantitative methods or qualitative methods can. Braun and Clarke (2006) created a very popular thematic analysis framework which has since been used to identify patterns of meaning in qualitative data, and is used in analyzing interview data on collaborative and organizational processes, including in interdisciplinary research contexts (Lyall et al., 2011; Bunders et al., 2010).

## METHODOLOGY

A mixed methods research design was used which included a quantitative based structured questionnaire and a qualitative based semi-structured interview to investigate the role of interdisciplinary collaboration in innovation and practical issues in technology, engineering and applied sciences. The participants were professionals and researchers from various applied-science backgrounds such as engineering, computer science, information technology, environmental sciences, and biotechnology. Using a purposive sampling strategy, participants with direct experience in interdisciplinary projects or research were selected, and a total of 185 quantitative responses were included in the data analysis after the data were screened for missing data and outliers.
Six constructs including interdisciplinary collaboration, knowledge integration, technological capability, research collaboration, innovation performance, and real-world problem-solving capacity were evaluated using the structured questionnaire. All items were adapted from scales used in the interdisciplinary research and innovation management literature and responded on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). The questionnaire was pre-tested before it was completely disseminated and reliability was tested by the Cronbach's alpha, where all constructs had an acceptable value of 0.70.
To complement findings from the quantitative analysis, a sub-sample of 18 participants was selected to reflect diversity across disciplines and across roles of collaboration, and interviewed semi-structuredly to understand the mechanisms that enabled knowledge sharing and integration across disciplines. Interviews were conducted using an open-ended guide with questions to elicit the participants' knowledge of interdisciplinary collaboration, their experiences with enablers and barriers to integration of knowledge, and their examples of innovative or problem-solving outcomes of cross-disciplinary collaboration. The interviews were recorded, fully transcribed and anonymized before being analyzed.
The quantitative data was analysed using SPSS. All constructs were subjected to descriptive statistics and Cronbach's alpha reliability coefficient and bivariate relationships between all study variables were explored using Pearson correlation analysis. A multiple regression analysis was then performed to identify the contribution of interdisciplinary collaboration, knowledge integration, technological capability and research collaboration to

innovation performance and problem-solving capacity at the 5% significance level. Thematic analysis, described by Braun and Clarke (2006) and comprised of six phases: Data familiarization, initial coding, identifying themes, review, refining and reporting themes, was used to analyse the qualitative interview transcripts. A subsample of transcripts was independently coded by two researchers to ensure coding consistency before full coding. The quantitative and qualitative results were then synthesized using a convergence-based mixed methods approach to gain a full understanding of how mechanisms for interdisciplinary collaboration became manifested in innovation and problem-solving results.

## RESULTS

To ensure the reliability of the quantitative constructs, a reliability analysis was conducted before hypothesis testing. Descriptive statistics, correlation and regression results are reported first to be followed by the qualitative results of the thematic analysis and then incorporated with the quantitative results.

***Table 1: Reliability and Descriptive Statistics of Quantitative Study Constructs (N = 185)***

| Construct | No. of Items | Cronbach's Alpha | M | SD |
|---|---|---|---|---|
| Interdisciplinary collaboration | 5 | 0.86 | 3.71 | 0.69 |
| Knowledge integration | 5 | 0.88 | 3.64 | 0.72 |
| Technological capability | 4 | 0.83 | 3.69 | 0.66 |
| Research collaboration | 4 | 0.81 | 3.58 | 0.74 |
| Innovation performance | 5 | 0.90 | 3.66 | 0.70 |
| Problem-solving capacity | 5 | 0.89 | 3.72 | 0.65 |

*Note.* M = mean; SD = standard deviation. All Cronbach's alpha values exceeded the 0.70 threshold, confirming acceptable internal consistency reliability.

All constructs exhibited high internal consistency (from 0.81 to 0.90, see Table 1), and means for the constructs showed generally positive perceptions of the participants about interdisciplinary collaboration and its outcomes. Pearson correlation coefficient (r) was used to calculate the correlations among the study variables.

***Table 2: Pearson Correlations Among Study Variables***

| Variable | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1. Interdisciplinary collaboration | — | | | | | |
| 2. Knowledge integration | 0.64** | — | | | | |
| 3. Technological capability | 0.51** | 0.55** | — | | | |
| 4. Research collaboration | 0.57** | 0.59** | 0.53** | — | | |
| 5. Innovation performance | 0.66** | 0.71** | 0.58** | 0.61** | — | |
| 6. Problem-solving capacity | 0.62** | 0.68** | 0.56** | 0.60** | 0.73** | — |

*Note.* N = 185. **Correlation is significant at the 0.01 level (two-tailed).

As reported in Table 2, interdisciplinary collaboration, knowledge integration, technological capability, and research collaboration were all statistically and positively related to innovation performance and problem solving capacity, and knowledge integration had the strongest bivariate relationships with both the innovation performance and the problem solving capacity.

***Table 3: Multiple Regression Results Predicting Innovation Performance and Problem-Solving Capacity***

| Predictor | Innovation Performance (β) | Problem-Solving Capacity (β) |
|---|---|---|
| Interdisciplinary collaboration | 0.26** | 0.22** |
| Knowledge integration | 0.34** | 0.31** |
| Technological capability | 0.16* | 0.14* |
| Research collaboration | 0.18** | 0.17** |

| Predictor | Innovation Performance (β) | Problem-Solving Capacity (β) |
|---|---|---|
| $R^2$ | 0.57 | 0.60 |
| F | 59.42** | 67.85** |

*Note.* N = 185. β = standardized regression coefficient. *p < .05. **p < .01. Variance inflation factor values for all predictors ranged from 1.38 to 2.14, indicating no multicollinearity concerns.

The four predictors accounted for 57% of the variance in innovation performance and 60% of the variance in problem-solving capacity as seen in Table 3. Knowledge integration was the top predictor of both outcomes (β = .34 and β = .31, respectively) with the other three items (interdisciplinary collaboration, research collaboration, and technological capability) remaining statistically significant independent predictors.

***Table 4: Summary of Qualitative Themes Identified Through Thematic Analysis of Interview Data (n = 18)***

| Theme | Description | Participants Referencing Theme |
|---|---|---|
| Structured collaborative platforms | Formal project structures, shared digital tools, and dedicated interdisciplinary spaces that provided regular opportunities for cross-disciplinary interaction | 16 |
| Boundary-spanning communication | Deliberate translation of discipline-specific terminology and concepts to enable mutual understanding among collaborators | 15 |
| Shared conceptual frameworks | Development of common models, goals, or problem framings that aligned disparate disciplinary perspectives | 14 |
| Trust-based relationship building | Informal relationship development and psychological safety that encouraged open knowledge exchange across disciplines | 13 |
| Institutional support structures | Organizational incentives, leadership endorsement, and resource allocation that legitimized and sustained interdisciplinary work | 12 |

*Note.* Themes were derived using Braun and Clarke's (2006) six-phase thematic analysis framework. Participant counts reflect the number of interviewees whose transcripts contained content coded to each theme.

From the interview data, five common processes were identified, as described in Table 4, that were used to explain how participants saw knowledge sharing and integration between disciplines could be facilitated. Structured collaborative platforms and boundary spanning communication practices were the most common mechanisms, followed by shared conceptual frameworks, trust-based relationship building and institutional support structures. Knowledge integration was consistently viewed as an active and intentional process, one that involved making connections between, and translating, disciplines, not as a consequence of the disciplinary co-location.

The quantitative and qualitative results showed that there is a high level of convergence, where the quantitative result showed that knowledge integration is the most important predictor of innovation and problem solving outcome, which is reflected in the qualitative results where the participants emphasized that the knowledge integration as a process in actual practice is carried out through the use of structured platforms, shared frameworks, and communication practices.

## DISCUSSION

Overall, the quantitative results corroborate the results from the literature on interdisciplinarity and team science, and show a significant association between interdisciplinary collaboration, knowledge integration, technological capability and research collaboration with innovation performance and problem-solving ability in technology, engineering and applied-science contexts. The results from the present work confirm theoretical claims that understanding the interdisciplinary nature of knowledge integration—rather than the mere co-presence of disciplines—is the most important link between interdisciplinary collaboration and innovation, as expressed for both outcome variables (Bammer, 2013; MacLeod, 2018).

The qualitative thematic results offer a mechanistic explanation for this quantitative pattern, by highlighting the need for structured collaborative platforms, deliberate boundary-spanning communication, and shared conceptual frameworks in order to achieve knowledge integration in practice, as proposed by Pennington (2008) and proposed by Repko and Szostak (2020). The importance of establishing a trust-based relationship as a facilitating

mechanism also reinforces Gray's (2008) conclusion that collaborative leadership and relational trust are key, but overlooked, aspects of good interdisciplinary practice.
The merging of the two strands found in this research supports the importance of using mixed-methods approaches to gain insights into other organizational phenomena, as suggested by Creswell and Plano Clark (2018) and Tashakkori and Teddlie (2010), to study interdisciplinary collaboration. Additionally, the results align with existing studies that find that organizational incentives and leadership support are strong determinants of the successful implementation and translation of interdisciplinary collaboration into innovation outcomes (Siedlok & Hibbert, 2014; Bridle et al., 2013). These results indicate that investments in structural opportunities for cross-disciplinary collaboration, in relationship building, and in institutional arrangements are needed simultaneously and not independently of one another to facilitate interdisciplinary innovation in technology, engineering, and applied sciences (TEAS) (Salazar et al., 2012).

**CONCLUSION AND RECOMMENDATIONS**

This mixed-methods study showed that the 4 factors of interdisciplinary collaboration, knowledge integration, technological capability and research collaboration are all significant predictors of innovation performance and real-world problem-solving abilities of technology, engineering, and applied sciences professionals and researchers, with knowledge integration being the most influential predictor. This integration is further demonstrated in practice on the basis of the qualitative thematic analysis which identified structured collaborative platforms, boundary-spanning communication, shared conceptual frameworks, trustful relations and institutional support structures as enabling mechanisms to translate interdisciplinary engagement into innovation outcomes. The results indicate that deliberate investments in structured collaborative platforms and shared conceptual framework that proactively enable knowledge integration are recommended to organizations and research institutions aiming to foster interdisciplinary innovation, which is often assumed to emerge from interdisciplinary co-location. In addition, the fact that these are key elements in effective cross-disciplinary engagement, institutional leaders are strongly encouraged to strive for building up trust-based collaborative relationships and ensuring that interdisciplinary work is explicitly encouraged and supported through infrastructure and incentives within the institution. Future studies could continue this mixed methods design by exploring it in a longitudinal context, as a means to follow the evolution of interdisciplinary collaboration mechanisms throughout the life cycle of a given technology and engineering project, as well as how the dynamics vary when it comes to the various combinations of disciplines and organizational context.

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