IIAI Open Conference Publication Series
IIAI Letters on Institutional Research
Vol. 005, LIR471
DOI: https://doi.org/10.52731/lir.v005.471

Contradiction and Abduction: Catalyzing the Data-Driven and Hypothesis-Driven Approach in Eduinformatics

Kunihiko Takamatsu [*], Sayaka Matsumoto [*], Tsunenori Inakura [*], Katsuhiko Murakami [†], Shotaro Imai [*], Ikuhiro Noda [‡], Kenya Bannaka[‡], Yasuhiro Kozaki [§], Aoi Kishida [**], Kenichiro Mitsunari [‡], Masato Omori [‡], Masao Mori [*], Yasuo Nakata [‡]

Abstract

The increasing use of data in educational research, framed within fields like Eduinformatics, necessitates effective strategies for hypothesis generation within the cyclical data-driven and hypothesis-driven approach. However, the crucial step of forming novel hypotheses often relies on Abduction, a form of inference known to be challenging. This paper addresses the difficulty of abductive hypothesis formation by exploring potential aids. Through conceptual analysis grounded in Eduinformatics and IR Philosophy, we investigate the role of contradiction in facilitating this process. We argue that constructively engaging with contradictions—whether they arise from data conflicting with existing theories or from differing normative viewpoints—serves as a powerful catalyst for the "surprise" that triggers abduction. The development of the Significant Other Groups (SOGs) concept is presented as an illustrative case where analyzing contradiction led to new theoretical insight. This study concludes that reframing contradiction not as an obstacle but as a vital prompt for inquiry offers a valuable perspective for enhancing creativity and knowledge generation, thereby aiding abduction within the research cycle in Eduinformatics. This perspective helps reconstruct the cycle linking hypotheses and data by leveraging the generative power inherent in contradiction.

Keywords: Abduction, data-driven and hypothesis-driven approach, Eduinformatics, Contradiction

1 Introduction

1.1 Eduinformatics

The landscape of higher education is undergoing significant transformation, particularly spurred by the societal shift towards Society 5.0, an era emphasizing the integration of cyber and physical spaces. Within this evolving context, the role and methodologies of Institutional Research (IR) are also being re-evaluated. Traditional approaches often struggle to bridge the gap between practical institutional needs and theoretical advancements. To address these challenges and lev-

[*] Institute of Science Tokyo, Tokyo, Japan
[†] The University of Tokyo, Tokyo, Japan
[‡] Kobe Tokiwa University, Kobe, Japan
[§] Osaka Kyoiku University, Osaka, Japan
[**] Kobe City Nishi-Kobe Medical Center, Kobe, Japan

erage the increasing availability of educational data, a novel interdisciplinary field termed "Eduinformatics" has been proposed [1].

Eduinformatics represents a synthesis of education and informatics, aiming to create a synergistic field that draws upon the problem-solving methods of informatics to address complex issues within education. It is conceptualized as an intersection where educational challenges meet data-driven analytical techniques, as illustrated in Figure 1 which depicts Eduinformatics bridging the two domains to link problems requiring solutions with problem-solving methodologies [2]. The core idea is to move beyond simply collecting data towards applying sophisticated analytical methods, derived from informatics, to gain deeper insights into student learning, institutional effectiveness, and overall educational processes. This involves not only analyzing existing student data but also actively developing new analytical methodologies specifically tailored to the unique contexts and goals of educational institutions.

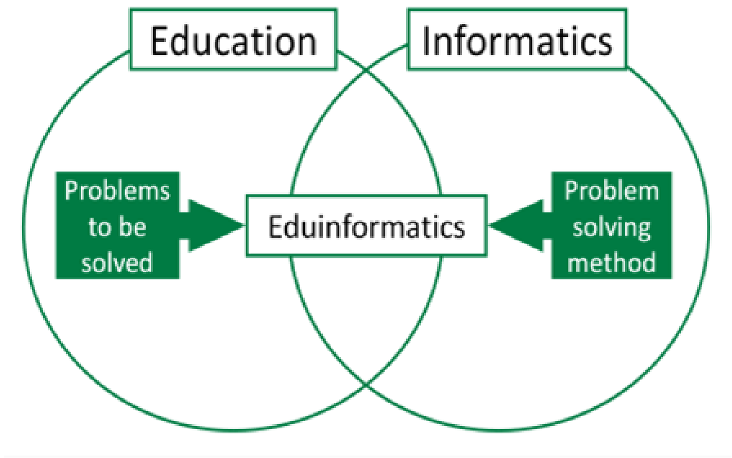

Figure 1: Conceptual representation of Eduinformatics as the intersection of Education and Informatics, adapted from [2].

The field was conceived to address observed needs within higher education institutions, particularly concerning the skills and knowledge required by IR professionals. Surveys indicated that practitioners desire capabilities extending beyond statistical analysis to include a broader understanding of higher education contexts. Eduinformatics provides a framework for integrating these technical and contextual dimensions. By combining the rigorous analytical power of informatics with the nuanced understanding of educational theory and practice, Eduinformatics seeks to offer fresh perspectives and more effective, data-informed strategies for institutional improvement and educational reform. It aims to equip educators and administrators with the tools and approaches necessary to navigate the complexities of modern higher education and harness data for meaningful advancements in teaching, learning, and institutional management. This interdisciplinary approach fosters a more holistic understanding, facilitating the development and application of novel solutions to persistent educational problems.

1.2 The Interplay of Data-Driven and Hypothesis-Driven Research

Scientific inquiry, including research within fields like Eduinformatics, often employs two complementary approaches: hypothesis-driven and data-driven research. Understanding the distinction and relationship between these approaches is crucial, particularly in an era characterized by large datasets ("big data") [3].

Traditionally, much scientific investigation has followed a hypothesis-driven pathway. This approach, as illustrated in the latter part of Figure 2, begins with the formulation of a specific hypothesis or question based on existing knowledge or observations. Researchers then design and conduct experiments or analyses specifically aimed at testing the validity of this hypothesis [4]. If the results do not support the initial hypothesis, the process iterates: the hypothesis is revised or a new one is constructed, leading to further experimentation. This cycle continues, refining understanding through directed investigation [4]. This method was the primary mode of research in many fields, such as life sciences, before the advent of large-scale data generation technologies [3].

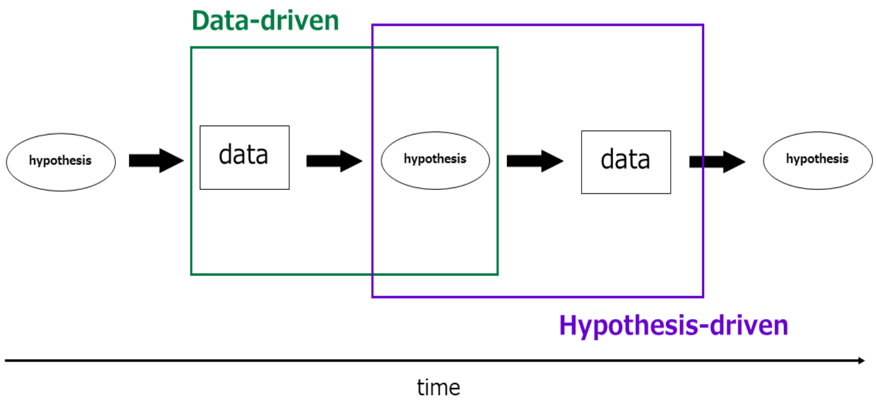

Figure 2: Schematic representation of data-driven and hypothesis-driven research approaches over time, adapted from [4].

The emergence of big data, exemplified by projects like the human genome sequencing, has catalyzed the prominence of the data-driven approach. In contrast to the hypothesis-driven method, data-driven research often starts with the data itself (Figure 2) [4]. Researchers explore large datasets to identify patterns, correlations, or anomalies, which then lead to the generation of new hypotheses. Essentially, the data serves as the primary source of inspiration for research questions, reversing the traditional sequence [4] . This approach has become increasingly relevant in education, where the widespread use of technologies like Learning Management Systems (LMS) generates vast amounts of student data, creating opportunities for data-driven discovery.

However, it is essential to recognize that these two approaches are not mutually exclusive but rather exist in a dynamic, cyclical relationship [4] [5]. As depicted in Figure 3, insights gained from data-driven exploration lead to new hypotheses, which can then be rigorously tested using hypothesis-driven methods. Conversely, the results (data) generated from hypothesis testing feed back into the pool of knowledge, potentially sparking new data-driven inquiries. This continuous cycle, where data informs hypotheses and hypotheses guide data collection and analysis, represents a powerful paradigm for advancing knowledge in complex fields like Eduinformatics [3], [5], [6], enabling both broad exploration and focused investigation. Understanding this interplay is fundamental to effectively leveraging data for educational improvement.

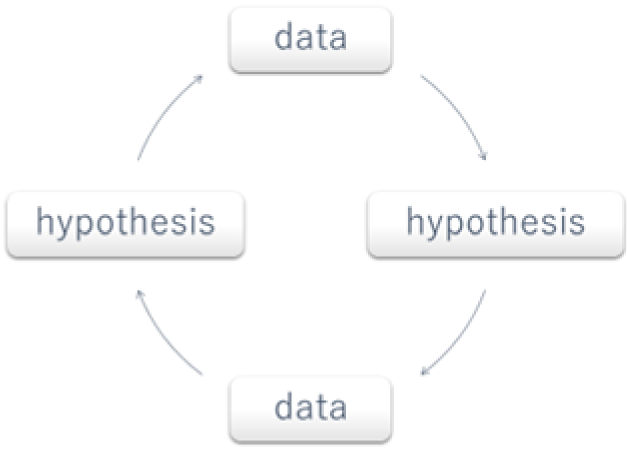

Figure 3: The cyclical relationship between data and hypothesis generation, adapted from [4].

1.3 Abduction and the Emergence of IR Philosophy

The cyclical interplay between data and hypotheses, as discussed previously (Section 1.2, Figure 3), highlights a critical juncture: the generation of novel hypotheses from data. While the data-driven approach leverages large datasets for inspiration [6], and the hypothesis-driven approach refines understanding through testing [5], the cognitive leap from observing data patterns to formulating a plausible, testable hypothesis remains a complex challenge. This process often involves more than straightforward deduction or induction; it requires a form of inference capable of generating new ideas or explanations.

Charles Sanders Peirce identified this type of reasoning as "abduction" or hypothetical inference [7]. He proposed it as a third fundamental mode of reasoning alongside deduction and induction [7]. Abduction involves observing a surprising fact or pattern within data and then inferring a potential rule or hypothesis that, if true, would explain that observation. Unlike deduction (which applies a general rule to a specific case to derive a necessary conclusion) or induction (which generalizes from specific instances to infer a probable rule), abduction generates potential explanations or hypotheses that are plausible but not guaranteed [7]. It is often described as an inference to the best explanation. In the context of the data-hypothesis cycle (Figure 3), abduction plays a crucial role, particularly in the data-driven phase where new hypotheses are sought from potentially complex or noisy datasets. However, effectively performing abduction is acknowledged to be difficult, often requiring intuition, creativity, and deep contextual understanding, making the systematic generation of valuable hypotheses challenging.

Recognizing the practical challenges and the evolving nature of IR in the era of Society 5.0 and Eduinformatics, a need arises to bridge the gap between the practical application of IR methods and the underlying theoretical and philosophical considerations. Historically, IR in Japan has often focused heavily on the practical aspects, such as the content of IR work, organizational positioning, and responses to accreditation evaluations, sometimes overshadowing deeper theoretical engagement. This mirrors historical developments in pedagogy during the transition from Society 2.0 to 3.0, where a divide existed between practical teaching techniques and theoretical/philosophical foundations[8], eventually bridged by figures like Herbart who sought to systematize pedagogy by integrating practical philosophy and psychology[8].

Drawing parallels to this historical evolution and acknowledging the current gap in IR [8], the concept of "IR Philosophy" has been proposed. IR Philosophy aims to establish IR as a more robust academic discipline by scientifically deriving theoretical insights from practical IR activities and continuously questioning the nature and goals of effective IR. It encourages a reflective approach that integrates technical skills with "contextual intelligence" and "issue knowledge"—a deep understanding of the educational environment and the specific problems being addressed. Within this framework, understanding the role and challenges of abductive reasoning in hypothesis generation becomes a key component. IR Philosophy, therefore, seeks not only to enhance the effectiveness of IR practice but also to build a stronger theoretical foundation for the field, potentially offering insights into complex processes like abduction within the specific context of higher education data analysis and reform. It advocates for learning from historical context, including Japan's own educational history, to better inform current practice and future theory, often leveraging insights from the related field of Eduinformatics [1], [2].

1.4 Research Question

As established, the effective use of both data-driven and hypothesis-driven research hinges on the cyclical generation and testing of hypotheses (Figure 3). A significant bottleneck in this cycle often lies in the transition from data analysis to hypothesis formulation. While data can reveal patterns and correlations, the leap to a meaningful, explanatory hypothesis frequently requires more than standard inductive or deductive logic.

This creative step aligns closely with the concept of abduction, as described by Peirce [7]. Abduction allows for the generation of novel explanations for observed phenomena, a process essential for scientific discovery but notoriously difficult to systematize or execute reliably. Existing logical frameworks often focus on continuous, inferential steps, whereas abduction represents a potentially discontinuous leap towards a new idea. Given the increasing complexity and volume of data available within Eduinformatics, coupled with the practical challenges associated with performing effective abduction, a critical question arises: How can this vital process of hypothesis generation from data be facilitated? Therefore, the central research question guiding this paper is:

Research Question (RQ): What frameworks, methods, or tools can effectively aid the process of abductive hypothesis formation within the data-hypothesis cycle in the context of Eduinformatics?

Addressing this question, it aims to provide practical support for researchers and practitioners seeking to leverage data more effectively for insight and innovation in education.

2 Methods

This study employs a conceptual analysis methodology to address the central research question concerning aids for abductive hypothesis formation within the Eduinformatics context. The core of the investigation involves a theoretical exploration of the mechanisms underlying the cyclical relationship between data and hypotheses, with a particular focus on the challenging transition where novel hypotheses are generated from observed data or contradictions.

The analysis is theoretically grounded in the principles of Eduinformatics and the emerging framework of IR Philosophy, as delineated in the introduction [1], [8]. Eduinformatics provides the interdisciplinary lens integrating educational problem contexts with informatics-based problem-solving approaches [1], while IR Philosophy guides the reflection on bridging practical research activities with deeper theoretical understanding, including the nature of scientific inference in institutional settings (Section 1.3) [8].

Specifically, this research synthesizes and analyzes existing knowledge drawn from several key domains. Foundational concepts of abduction, primarily drawing from the work of Peirce [7], are examined to understand its characteristics as a mode of inference distinct from deduction and induction and its role in generating novel explanations. The dynamics of data-driven and hypothesis-driven research paradigms [3], [5], [6] are reviewed to contextualize the specific point in the research cycle where abductive reasoning is most critical. Furthermore, the analysis incorporates relevant perspectives from the philosophy of science regarding hypothesis generation and the role of anomalies or contradictions as potential triggers for scientific discovery.

By critically examining and structuring these concepts through the frameworks of Eduinformatics and IR Philosophy, this study aims to identify potential pathways, conceptual tools, or framework characteristics that could facilitate the difficult but essential process of abductive hypothesis formulation in data-rich educational research environments. The approach is primarily theoretical, seeking to construct a coherent conceptual argument rather than relying on empirical data collection for this stage of inquiry.

3 Results and Discussion

This section addresses the research question regarding potential aids for the challenging process of abductive hypothesis formation within the data-hypothesis cycle. Drawing upon the conceptual analysis outlined in the methods, we propose that encountering and constructively engaging with contradiction serves as a primary catalyst for the abductive leaps necessary for generating novel insights in Eduinformatics.

3.1 Contradiction as a Catalyst: The Case of Significant Other Groups (SOGs)

A key "result" emerging from practical application within the Eduinformatics framework illustrates this principle. In a study focused on university reform, a significant contribution (including figure creation) was made by a graduate student. Typically, university reform processes primarily involve faculty and administrative staff, sometimes extending to current students or formally defined external stakeholders. Consequently, a contradiction arose regarding the graduate's role: prevailing "common sense" suggested that involving graduates (as alumni/alumnae) in such internal initiatives was inappropriate. This led to the decision that the graduate's contribution, despite its significance, would be recognized only in the acknowledgments section rather than through full co-authorship [9]. Instead of simply accepting or dismissing this conventional viewpoint, the researchers embraced the contradiction as an object of inquiry. They delved into the underlying reasons why common sense dictated the exclusion of graduates from such roles.

This critical examination of the contradiction between the graduate's actual contribution and the perceived norms led to a deeper understanding of stakeholder roles in university governance. It prompted the development of a new conceptual framework: Significant Other Groups (SOGs). SOGs were defined to include a broader range of participants (including faculty, staff, students, and graduates or external faculty) who genuinely wish to contribute to higher education development, moving beyond traditional, often interest-based, stakeholder definitions [9]. This novel concept, born directly from analyzing a point of contradiction, formed the core of a subsequent publication that received international recognition (Outstanding Paper Award at IIAI AIT 2020) [9].

This example serves as a concrete illustration of how confronting disagreement or contradiction—rather than avoiding or suppressing it—can be a fertile ground for generating new theoretical constructs and practical frameworks. The process involved questioning the premises of the "common sense" view that created the initial conflict.

3.2 Discussion: Contradiction, Abduction, and Creativity

The SOGs case exemplifies a broader principle crucial for hypothesis formation. When faced with data, ideas, or perspectives that contradict one's own or existing theories, the critical step is not dismissal but inquiry. This echoes philosophical approaches where resolving contradictions often involves examining differing premises, incorporating new information or contexts, differentiating specific cases, or achieving a synthesis that transcends the initial opposition (Aufheben).

This principle resonates strongly with the process of abduction. As discussed (Section 1.3), abduction is the form of inference often required to generate new hypotheses, particularly when existing data contradicts established theories or expectations. Charles Sanders Peirce, who formulated the concept, noted that abduction often begins with a "surprising fact" or an "unexpected observation" (CP 5.189) [10].

> Peirce: CP 5.189 Cross-Ref:††
>
> 189. Long before I first classed abduction as an inference it was recognized by logicians that the operation of adopting an explanatory hypothesis -- which is just what abduction is -- was subject to certain conditions. Namely, the hypothesis cannot be admitted, even as a hypothesis, unless it be supposed that it would account for the facts or some of them. The form of inference, therefore, is this:
>
> The surprising fact, C, is observed;
>
> But if A were true, C would be a matter of course,
>
> Hence, there is reason to suspect that A is true.

Such "surprise" inherently arises from a contradiction between what is observed and what is expected based on prior knowledge or hypotheses. Therefore, contradiction appears to be a key trigger, perhaps even a necessary condition, for initiating the abductive process that leads to new hypotheses.

Abduction is often characterized as a non-continuous or discontinuous logical leap, distinguishing it from the more linear processes of deduction and induction; this inherent discontinuity contributes significantly to the difficulty generally associated with novel hypothesis formation [7]. Yet, fostering this abductive capability is increasingly vital in the context of profound societal shifts. We are currently navigating the transition from Society 4.0 (the Information Society) towards Society 5.0, a new human-centered societal model proposed by the Japanese government that deeply integrates cyberspace and physical space [11]. This transition, depicted conceptually in Figure 4, aims to balance economic advancement with the resolution of social problems through sophisticated systems. Internationally, similar concepts like Industry 5.0 are discussed, highlighting a global move towards societies where technology serves human well-being and sustainability alongside productivity.

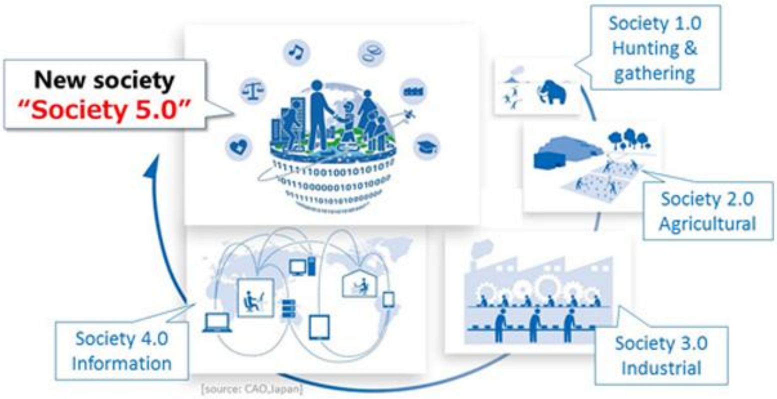

Figure 4: Conceptual diagram illustrating the progression towards Society 5.0, adapted from [11]

Successfully navigating and contributing to Society 5.0 requires skills and competencies that go beyond rote knowledge acquisition or proficiency in established procedures. Educational paradigms are shifting accordingly, with a strong emphasis placed on fostering 21st-century skills. International organizations like the OECD emphasize competency-based education, distinguishing between specific technical competencies required for jobs and broader core competencies clustered around delivery, interpersonal skills, and strategic thinking [12]. Within these frameworks, Creativity emerges as a particularly crucial element [13]. It is increasingly recognized as essential not just in artistic fields but across disciplines—including science, technology, engineering, and mathematics (often discussed within the STEAM educational approach)—for addressing complex, real-world problems that lack predefined solutions [13].

This demand for creativity is intrinsically linked to the ability to formulate novel hypotheses – the very outcome of successful abduction. Generating creative solutions or new lines of inquiry fundamentally depends on the capacity to look beyond existing data or theories and propose plausible new explanations or possibilities. Therefore, enhancing the ability to perform abduction is not merely a technical challenge for researchers but a core educational goal for preparing citizens capable of thriving in and shaping Society 5.0. Furthermore, this challenge is amplified as research methodology itself increasingly shifts towards data-driven paradigms [3], [5], [6].

While these paradigms provide unprecedented amounts of data, the critical step of extracting meaning and generating insightful hypotheses from that data—the abductive step—becomes even more central and demanding. Without effective hypothesis generation, data remains inert. Consequently, having effective triggers and aids for the difficult abductive leap is paramount for translating data into actionable knowledge and innovation. This underscores the importance of investigating catalysts, such as the constructive engagement with contradiction proposed in this paper, to support this vital cognitive process.

This analysis suggests that contradiction, often viewed negatively or as an error signal in many contexts (excluding specific logical methods like proof by contradiction), deserves re-evaluation within the framework of scientific discovery and Eduinformatics. It should perhaps be recognized not merely as an obstacle, but as a valuable catalyst for abduction. Embracing contradictions, analyzing their origins, and using them as explicit prompts for inquiry may represent a powerful strategy to aid researchers in formulating the novel hypotheses needed to advance understanding and drive innovation in education.

4 Conclusion

This paper sought to explore aids for the challenging yet crucial process of abductive hypothesis formation, particularly within the context of Eduinformatics where data-driven insights are increasingly sought. The central research question guiding this exploration was:

RQ: What frameworks, methods, or tools can effectively aid the process of abductive hypothesis formation within the data-hypothesis cycle in the context of Eduinformatics?

Based on the conceptual analysis and the illustrative case study of Significant Other Groups (SOGs) presented, this paper concludes that contradiction itself serves as a powerful, yet often undervalued, catalyst and aid for abduction. The key lies not simply in encountering contradiction—whether between data and existing theories, or between differing viewpoints and norms—but in the constructive engagement with it. By actively analyzing the sources and underlying premises of contradictions, rather than dismissing them, researchers can unlock pathways to novel insights and hypothesis generation. The development of the SOGs concept from a point of normative conflict provides a concrete example of this principle.

Therefore, this study proposes a reframing of contradiction: viewing it not as a mere error or obstacle, but as a vital trigger for the "surprise" that Peirce identified as the starting point of abduction. Cultivating a research disposition that actively seeks out and interrogates contradictions may offer a valuable strategy for facilitating the abductive leaps required for creativity and advancing knowledge within Eduinformatics and related fields.

Acknowledgement

This study was supported by JSPS KAKENHI (Grant Numbers: 25K13802 and 22H00077).

References

[1] K. Takamatsu, K. Murakami, T. Kirimura, K. Bannaka, I. Noda, L. R.-J. Wei, K. Mitsunari, M. Seki, E. Matsumoto, M. Bohgaki, A. Imanishi, M. Omori, R. Adachi, M. Yamasaki, H. Sakamoto, K. Takao, J. Asahi, T. Nakamura, *et al.*, "'Eduinformatics': A new education field promotion," *Bulletin of kobe Tokiwa University*, vol. 11, pp. 27–44, 2018, doi: 10.20608/00000958.

[2] K. Takamatsu, Y. Kozaki, K. Murakami, A. Sugiura, K. Bannaka, K. Mitsunari, M. Omori, and Y. Nakata, "Review of Recent Eduinformatics Research," in *2019 IIAI International Congress on Applied Information Technology (IIAI-AIT)*, 2019, p.

submitted.

[3] D. B. Kell and S. G. Oliver, “Here is the evidence, now what is the hypothesis? The complementary roles of inductive and hypothesis‐driven science in the post‐genomic era,” *Bioessays*, vol. 26, no. 1, pp. 99‐105, 2004.

[4] K. Takamatsu, I. Noda, K. Bannaka, K. Murakami, T. Kirimura, T. Kunisaki, R. Kozaki, S. Matsumoto, A. Kishida, H. Ito, A. Ito, S. Imai, K. Mitsunari, M. Omori, M. Mori, and Y. Nakata, “Abduction, abstract degree and urgency matrix (ABDU-M) for flexible/agile higher education reform based on eduinformatics,” in *Intelligent Sustainable Systems*, Singapore: Springer Nature Singapore, 2024, pp. 471–478. doi: 10.1007/978-981-99-8031-4_41.

[5] Y. Nakata, K. Bannaka, T. Kunisaki, T. Kirimura, and K. Takamatsu, “Data-driven approach essential for mathematical and data science education in basic nursing education: to avoid a belief conflict between methodologies,” *Bulletin of Kobe Tokiwa University*, vol. 15, pp. 12–19, 2022, doi: 10.20608/00001150.

[6] Y. Nakata, K. Bannaka, and K. Takamatsu, “Minimum essentials for mathematical and data science education in basic nursing education: Based on model curriculum （literacy level） which cultivate mathematical, data science, and artificial intelligence （AI）,” *Bulletin of Kobe Tokiwa University*, vol. 14, pp. 38‐46, 2021.

[7] C. S. Peirce, *Collected Papers of Charles Sanders Peirce, vol.2*, 2nd ed. Harvard Univ. Press, 1932, p. ¶776.

[8] K. Takamatsu, K. Tion, K. Bannaka, K. Murakami, T. Kirimura, R. Kozaki, S. Matsumoto, A. Kishida, H. Ito, and Y. Kozaki, “Proposing a New Field: Institutional Research (IR) Philosophy based on Eduinformatics: Bridging the Gap Between Practice and Theory in IR,” *IIAI Letters on Institutional Research*, vol. 4, no. LIR218, pp. 1–12, 2024, doi: 10.52731/lir.v004.218 Proposing.

[9] K. Takamatsu, K. Murakami, I. Noda, K. Bannaka, Y. Nakata, Y. Kozaki, A. Kishida, H. Kabutoya, K. Mitsunari, and M. Omori, “New Proposal of University Reform by Significant Other Groups in Eduinformatics,” *International Journal of Institutional Research and Management (IJIRM)*, vol. 5, no. 1, pp. 96–105, 2021, doi: 10.52731/ijirm.v5.i1.681.

[10] C. S. Peirce, “Abduction and Induction,” in *Collected Papers of Charles Sanders Peirce, Volume V: Pragmatism and Pragmaticism*, C. Hartshorne and P. Weiss, Eds. Cambridge, MA: Harvard University Press, 1934, pp. 117–118.

[11] Cabinet Office in Japan, “Society 5.0.” 2016. Accessed: Apr. 01, 2025. [Online]. Available: https://www8.cao.go.jp/cstp/english/society5_0/index.html

[12] Oecd, “About Technical Competencies in competency framework.” http://www.oecd.org/careers/competency_framework_en.pdf (accessed Apr. 01, 2025).

[13] D. Aguilera and J. Ortiz-Revilla, “STEM vs. STEAM education and student creativity:

A systematic literature review," *Education Sciences*, vol. 11, no. 7, p. 331, 2021, doi: 10.3390/educsci11070331.