Integrating Theory and Structured Inquiry in Computer Science Ph.D. Research

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When applied appropriately, theory serves as a lens for facilitating a structured and informed assessment of research applications. Many products of computer science research often undergo what may seem like sudden advancements, such as the rapid evolution of commercial artificial intelligence. Importantly, these developments come from extensive, theory-based research conducted by scholars, including those at the doctoral level; it is likely that commercial artificial intelligence developments, such as ChatGPT, utilized Machine Learning Theory as a lens for research into how to design their artificial intelligence models.

Theories do not emerge from thin air or manifest without foundation. Theory develops through methodical investigation, informed by well-crafted problem statements, purpose statements, and research questions. Theory constitutes a recognized set of principles implemented through logic and fair reasoning. However, it is important to remember that theory is not law. Theories may contain gaps or limitations, and the utility of these theories is constantly evaluated through continued application, where sometimes extending theories is necessary for different scenarios. With time, successful application of a theory only secures its credibility, while lack of relevance or use may render it obsolete.

In computer science at the doctoral level, theory directs investigation and broadens the discipline by continuously providing proven frameworks that enable necessary and structured inquiry; theory and inquiry are iterative, and as the field expands, established theories are utilized to advance the discipline/extend knowledge in the field. As computer science evolves, the application and revision of theory remain ever so important in a time of constant sudden advancement.

Research Statements and Questions

Problem Statement

Meaningful doctoral-level research includes an articulated problem statement, which is necessary for shaping the direction of the study. National University (n.d.) states that a problem statement should describe a specific, evidence-based, real-life issue, explain the consequences of allowing the problem to persist, and identify what knowledge is required to address it.

Not every problem is worth researching; this distinction is important in computer science. For example, while a problem such as designing a programming language that only works during a full moon is feasible, no social, ethical, or scholarly relevance is required for a doctoral-level inquiry. On the contrary, algorithmic bias in machine learning for criminal justice is a research-worthy problem as it is a real-life problem supported by data and has clear consequences if left unaddressed.

Hu et al. (2020) provide a case study that explores the public perception of police behavior during traffic stops modeled with logistic regression and machine learning. They find what points to negativity bias and procedural justice as important factors shaping perceptions influencing the perceived fairness of law enforcement practices. The study encapsulates a specific, evidence-based, real-life problem, the interworking of a good problem statement.

Purpose Statement

The purpose statement clarifies what will be done to address an identified problem and how research will be conducted (National University, n.d.). It may be written in either qualitative or quantitative form. The purpose statement outlines the research design or methodology needed to explore the problem. For example, it might apply a theoretical framework to guide a study on algorithm performance or data storage practices across distributed computing environments. The nature of the study, qualitative or quantitative, can similarly be described as exploratory or explanatory.

A qualitative purpose statement is often used to explore the implications of a problem. It utilizes “open-ended” language (National University, n.d.) to capture the depth and complexity of experience or behavior. This is relevant in computer science areas such as human-computer interaction where a user's experience, perception, or behavior is examined. For quantitative purpose statements, “close-ended” language examines a mathematical or measurable relationship. It is for studies that wish to determine the impact of variables, for example, when studying the efficiency of an algorithm across data sets or system performance under different conditions, which ever they may be. A particular approach's suitability relies upon the research type the researcher intends to pursue.

Research Questions

The term “research question” is simple in principle or self-explanatory. However, a strong research question must be “clear, focused, concise, complex, and arguable” within a specific field (National University, n.d.). In computer science, research questions complement the problem and purpose statements by guiding the inquiry and direction of the study. For example, a question like “What is an efficient database system?” is overly broad and lacks complexity and clarity. A better version of this question may be, “What is the effect of providing agentic AI tools for support staff in higher education settings?” This question is specific in a real-world context, balances complexity and clarity, and invites argument through different perspectives.

Theoretical Framework in Computer Science

National University defines a theoretical framework as the "lens by which a study is developed" (Grant & Osanloo, 2014, as cited in National University, n.d.). In other words, it provides the conceptual (in nature, not framework) structure that shapes the direction and scope of a research study. The theoretical framework guides how the problem is examined, data is interpreted, and conclusions are drawn. Rather than simply presenting existing theories, the framework connects theories to a list of specific study objectives the researcher defines to form a basis for methodological decisions and research questions.

For computer science, theory can often feel abstract, not to be confused with the concept of abstraction, or disconnected from real-world relevance. Maurer (2021) observed that theoretical computer science may be perceived as presenting "theory for theory's sake," which can frustrate students seeking practical skills in their "Foundations of Computer Science" course. Nevertheless, theoretical computer science remains essential. At Baylor, Maurer redesigns the course to emphasize the practical use of theoretical concepts, specifically for concepts like finite state machines and push-down automata, as valuable tools that expand the problem-solving ability of modern computer scientists. This is important for understanding the role of a theoretical framework in computer science, which in this case is used as a tool for structured, relevant, and impactful research and practice.

What value does a theoretical framework hold for a doctoral-level computer science student? Every doctoral student anticipates eventually writing a dissertation. Without a theoretical framework, students lack a critical tool for developing research that meaningfully connects prior theory to new problems. This connection allows researchers to bridge gaps, set work in established thought, and contribute meaningful and lasting advancements to the field.

Relevant Theories to Computer Science

Human-computer interaction is one of the field's most enduring and critical areas, focusing on the interconnection between humans and computers. More than ever, modern applications prioritize intuitive and efficient interaction, and theoretical frameworks are essential in connecting human cognition to technology or computer design. For example, Information Processing Theory, which examines how users receive, process, and retain information, offers value in guidance for designing interfaces that align with cognitive capabilities (Kretchmar, 2021). Similarly, the Technology Acceptance Model and Cognitive Load Theory embrace human-computer interaction by highlighting the psychological and perceptual parameters influencing system usability, human engagement, and adoption.

Information Processing Theory

In the article *Deployment of Information Processing Theory to Support Adaptive E-Learning Systems: Feasibility Study*, Mwambe (2024) explores how Information Processing Theory serves as a theoretical lens for understanding how users, specifically students, perceive, process, and retain digital content. The study illustrates how the Information Processing Theory can inform the development of adaptive e-learning systems by aligning design features with cognitive preferences such as attention, interactivity, and cognitive load. In this study, Mwambe demonstrates that tailoring multimedia content to “Generation Z” learners improves the learning outcomes among ~100 participants. Constructs such as short-term and long-term memory, bioinformatics, and engagement are key in the design of the ‘DIT-eLMS’ platform. This research underscores the value of the Information Processing Theory in human-computer interaction as it effectively connects theoretical insight with system development.

Technology Acceptance Model

In their study, *Technology Acceptance Model in Government Context*, Amali et al. (2022) demonstrate how the Technology Acceptance Model can guide research on adopting information systems in government institutions. The study focuses on IT governance, analyzing how perceived usefulness, perceived ease of use, and behavioral intention influence the actual usage of digital computing systems. Though the context is rooted in information systems and public administration, the theoretical framework is directly relevant to computer science, particularly in human-computer interaction, understanding where human behavior and interaction is critical. The Technology Acceptance Model framework utilized in this study offers insight into where users accept or reject digital systems to design and evaluate usable and practical technology with existing hypotheses between states such as “Perceived Ease of Use (PEOU)” and “Attitude Toward Using Technology (ATUT)” (Amali et al., 2022).

Cognitive Load Theory

Cognitive Load Theory (Leppink, 2017) is notably relevant to computer science education due to the cognitive demands of learning computer programming. Berssanette and de Francisco (2022), in their literature review, *Cognitive Load Theory in the Context of Teaching and Learning Computer Programming*, examine how Cognitive Load Theory is applied to improve instructional design in programming education. The findings from this review highlight key concepts of the theoretical framework, including underlying and extraneous cognitive load, memory limits both short and long-term, and schema construction, as essential to understanding how learners process complex programming tasks. The study highlighted the effectiveness of such with worked examples and subgoal labeling to reduce learner overload and improve learning outcomes. Cognitive Load Theory provides an efficient theoretical framework that is informative for educational methodology and system design, reinforcing the value of human-computer interaction research in computer science.

Peer-Reviewed Articles

Information Processing (Learning) Theory

Information Processing Learning Theory is an instructional adaptation of the previously mentioned Information Processing Theory. It is a practical abstraction of this theory, reflecting how abstraction operates in computer science.

Key Constructs:

- Sensory Encoding: Translating external stimuli into internal representations.
- Rehearsal: Repetition of concepts to reinforce memory.
- Chunking: Grouping information into manageable units.
- Feedback & Assessment: Evaluating and refining understanding.

Variables:

- Independent: Learning model structure (e.g., compare-contrast, spaced repetition).
- Mediating: Cognitive load, engagement level.
- Dependent: Recognition accuracy, learning retention.

Research Goals:

- Optimizing human-computer interaction, improving how users learn to interact with complex or unfamiliar systems through instruction design and cognition.

In their study, Moon et al. (2025) applied this theory to develop a learning model for visual-to-auditory sensory substitution, a technology designed to assist visually impaired users in interpreting visual information through auditory signals. Participants in the study exhibited improvement in short-term learning compared to those engaged in randomized repetition learning. This illustrates that theory-based learning, a derivative of the significant Information Processing Theory in computer science, has a meaningful impact on human-computer interaction from a theoretical perspective.

Technology Acceptance Model

The Technology Acceptance Model was initially proposed by Fred Davis (1986). It aims to explain users' acceptance of technology with the following constructs and influence on behavioral intentions.

Key Constructs:

- Perceived Usefulness (PU): Belief that using the system will enhance performance.
- Perceived Ease of Use (PEOU): Belief that using a system will be effort-free.
- Attitude Toward Use (ATU): User feelings toward using the system.
- Behavioral Intention (BI): The intention to use a system in the future.

Variables:

- Independent: PU, PEOU.
- Mediating: ATU.
- Dependent: BI (and actual usage).

Research Goals:

- To determine which factors most significantly influence technology adoption in educational or institutional contexts.

In the study by Adouani and Khenissi (2024), TAM was extended to include additional variables to improve predictive power for modern (online) learning environments. The framework Davis provided helped identify student attitudes toward the e-learning platform.

Cognitive Load Theory

Data structures are a core concept of computer science education, but they present significant cognitive challenges for students due to their algorithmic/abstract nature. Arévalo-Mercado et al. (2023) applied Cognitive Load Theory in the design and testing of a tool that aimed at reducing cognitive overload when learning about linked lists, a “simple” data structure.

Key Constructs:

- Intrinsic Load: Difficulty inherent in the content.
- Extraneous Load: Load imposed by how information is presented.
- Germane Load: Effort to learning and schema development.
- Split Attention Effect: Mental intervention when learners must join separated sources of information.

Variables:

- Independent: Design of instruction (e.g., integration of code and diagrams).
- Mediating: Learner’s cognitive load level.
- Dependent: Learning outcomes (performance, schema construction).

Research Goals:

- Reducing unnecessary mental effort and improving learning outcomes.

The tool was designed using the Split Attention Effect from Cognitive Load Theory, which emphasizes reducing cognitive load caused by jumbled instruction materials. By utilizing node diagrams and example code within an interface, the researchers helped students form stronger mental schemas and reduce cognitive load. The experimental group showed statistically significant improvements ($p = 0.000$) in test scores compared to the control group. This study showed how Cognitive Load Theory can assist instructional design in a computer science education, reinforcing practical use in human-computer interaction contexts.

Conclusion

Theories, and thus theoretical frameworks, serve as the backbone of doctoral-level research in computer science, providing structures to explore complex problems. Currently, the evolution of technology seems to outpace reflection. However, research that utilizes theoretical frameworks to provide structure is happening daily to support these advancements. Information Processing Theory, the Technology Acceptance Model, and Cognitive Load Theory are only three of those that connect inquiry to application. Whether guiding the design of online learning systems, evaluating user adaptation, or shaping education, as demonstrated in Maurer (Baylor University) and Arévalo-Mercado’s work, theory assists research to be methodologically sound and impactful. For doctoral research in computer science, linking inquiry with theory and its frameworks is essential for contributing meaningful knowledge to the field.

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