# Interleaving Lenses to Scale Our Units of Analysis for Engineering Education Improvement

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It is clear from multiple sources that the current state of engineering education is not preparing students for useful practice in the 21st century [e.g., 1-3]. One of the key drivers of this is the large barrier that exists between the research and the implementable action items developed by practitioners [4, 5]. Changing research, practice, and forming stronger connections between them, at all scales, is required to close the gap between the engineers we are producing today, and the graduates industry is seeking.

How then do we establish a defined link between research and practice that allows for both the development of new ideas and outcomes that are required for impactful organizational change? At its core, the observation and analysis of education is a study of experience [6]. These experiences cannot simply be analyzed with reductionist research methodologies on individual segments of an organization, but instead, require research methods that fully acknowledge the experiences that occur between the interactions of organizational segments [6, 7]. The consideration of experience is crucial due to the vital data that exists within dynamic organizational relationships within our own organizations of learning [5, 6, 8]. Academia has already been utilizing tools to capture experiences for years (e.g., interviews, surveys, ethnographies, and observations), and even though these tools aid in providing the context of gathered research data, the barrier between research to practice remains [9]. In this paper we use engineering management inspired thinking and research lenses to combine the perspective lenses of user experience design, open systems theory, complex systems theory, and narrative analysis. This multi-lens environment is particularly suited for accurately understanding and driving change within the engineering education domain at all levels. This conceptual study explores the implications of binding the four perspectives together and applying them to learning organizations. As part of this process, we form a common dialect to allow for future framework contributions. The following sections describe the four lenses, connects them to each other and engineering education, and suggest pathways for continued leveraging of core engineering management knowledge in the continued innovation of engineering education.

The theoretical lenses can be broadly thought of as viewpoints or perspectives in which we analyze an event. This section will provide necessary context on the perspective lenses of complexity theory, open systems theory, user experience design, and narrative analysis.

## Complexity Theory

> "Causes always occur in bundles, and only in the presence of a whole series of conditions guarantee success. Linear thinking is not good enough, we need to think of the causal network in which multiple factors make each other operational. [10, Pg. 231]"

Complex System Theory (CST) sets organizational expectations from the way individual elements of a system interact with other internal system elements, the context that those interactions exist within, and the overall system impacts made by system elements. This is significant as a large amount of system data is located within the organizational relationships of the system [5]. To determine if a system is complex, Ciller [7] developed a set of ten conditions:

1) Complex systems contain a large number of elements, and, at large scales, conventional means of analysis cease to assist in their understanding.
2) The elements within the system must interact dynamically.
3) The levels of influence are significant, meaning each element is influenced by several other elements.
4) Interactions have importance, and non-linearity exists in a capacity that allows for small decisions to have larger impacts on the system.
5) Interactions are usually short in range, typically bounded by immediate neighboring elements within the system, resulting in enhancing, suppression, or alteration as interactions flow through the system.
6) Feedback loops exist within the system.
7) Complex systems are also typically open systems; they frequently interact with their external environment.
8) Operation is far from equilibrium; a constant flow of energy is required for sustainment.
9) Complex systems have an evolution over time, which is responsible for current behavior.
10) Each element of the complex system only responds to the information it has locally and is often ignorant of the behavior of the system as a whole.

The lens of complex system theory focuses on the many factors that lead to systems within its domain and how the interactions of internal elements influence the overall system design.

**Open Systems Theory**

> "Social systems have structure, but it is a structure of events rather than physical parts, a structure therefore inseparable from the functioning of the system.[11]"

Open Systems (OS) are systems that are heavily influenced by and frequently interact with their external environment [12]. An important aspect of the system's relationship with the environment is the cyclic behavior the system inherits: receiving input, undergoing internal transformation, producing an output, and processing feedback. Each component influences those immediately succeeding it within the cycle [13, 14]. The occurrence of such behavior is embedded in the fact that open systems often intrinsically develop control processes when met with deviations from the environment, which allows them to reach a state of equilibrium [13]. Organizations that are open contain the following characteristics:

- They scan and sense changes in a. task or contextual environment [13].
- They manage and bridge critical boundaries as well as areas within them of interdependence [12, 15].

- They develop operational and strategic responsibility for internal areas [12, 15].

The lens of open systems theory focuses on the considerations that must be made between the system and its surrounding environment, both internal and external to the system. It also aids in the identification of those internal and external components.

**User Experience Design**

> "In a general sense, when one asks what it means to study education, the answer is to study experience.[6]"

If, on the fundamental level, the exchange of knowledge is one that is truly rooted in experience of those engaging in learning, shouldn't the development of user-facing content within our systems be looked at with the consideration of the user in mind? User experience design (UXD) focuses on the interaction between any system, it's user, and their context, or in a greater scope the balance of the relationship between an organization and its users [16, 17]. The purpose of applying user experience design to a system is primarily to ensure the sustainability and improvement of such relationship [18].

One model of user experience design created by Garret [16] breaks the layers of any user experience up into five main planes, together the planes provide a conceptual framework for answering user experience problems and provides the tools to develop solutions to the existing problems. The five planes consist of the strategy plane, the scoping plane, the structure plane, the skeleton plane, and the surface plane. Each plane builds off of one another, starting with the strategy plane to develop the information required to move on to the next stage of the user experience design process. The planes were originally constructed for the development of software, but their applications are much more diverse and expand into the scope of general user experience design [16]. The planes of user experience design can be summarized as:

- **The strategy plane** is where the goals of the organization, and the goals of the user are described.
- **The scoping plane** aims to answer the question "What are you going to make to meet the identified goals?" This includes the functions of the developed system, and the content required by the system.
- **The structure plane** is where we identify the concrete factors of what users will experience. This includes how the system will respond to the user, and how the user steps through the system to get to the end goal.
- **The skeleton plane** is where functionality begins to take its form. On this plane we identify the actions a user takes to accomplish a specific task, how a person navigates from where they currently are to another part of the system, and how information is presented to facilitate completion of navigation and tasks.
- **The surface plane** deals with how an individual's senses play into their overall experience. This includes how visual and auditory stimuli improve the components they experience within the system.

The lens of user experience design focuses on methods and actions that can be utilized to drive tangible outcomes based upon the input of information directly from those who would be receiving the outcomes. User experience design also outlines important considerations at each stage during the development of a product, service, etc.

**Narrative Analysis**

> "From a social perspective, stories are a key mechanism through which human experience has been shared for generations.[19]"

Qualitative research frameworks contain the ability to capture the complexity of human behaviors in a capacity not possible by traditional quantitative approaches that are rooted solely in the reduction and randomized control of a population [20]. In the field of Narrative Analysis (NA), stories are observed as a key mechanism in which we share our human experience with others [19, 21]. Information passed between people by narrative stories not only provide insight into the specific actions and their effects on an individual, but also how their emotions or their psychology influence their greater experience. Insight is also given into the network of relationships or influential pressures that were not clearly observable throughout the presented experience.

Hinchman and Hinchman [22] formally defined narratives as "discourses with a clear sequential order that connects events in a meaningful way for a definite audience, and thus offer insights about the world/peoples experience of it." Today, an individual narrative may be a story, a paragraph of text, an image, or any other response a person has to a prompt. A prompt would be the initial question and could be anything from "Tell us about your experience learning in college", to "Tell us about your experience with a specific piece of material within your engineering design course", to "Why did you enroll in program?" The prompt is directly tailored to the scope of the research question and aims to provide information in the larger context of where that phenomenon occurs [21]. There are two primary mindsets used in NA, "Paradigmatic Narrative Analysis" and "Alternate Narrative Analysis." A principal investigator with the paradigmatic mindset treats all captured narrative as a collective pool of information and has the goal of identifying common themes that exist between the narratives [21]. While the paradigmatic PI focuses on observing a combination of narratives to drive conclusions, the PI with a narrative mindset focuses inward by treating each narrative as its own source of information and aims to find core elements within each narrative to drive their conclusions [21]. Whether a paradigmatic or alternate mindset is applied to narratives, the production of data extends from just the narratives themselves to the analysis provided by the PI [23]. Our ability to verify the resulting data stems from the continuous representation and scaling of narratives as data is extracted from them, establishing a clear path between the provided narratives and the interpretation constructed by the PI [23].

**Viewing Engineering Education Through Our Lenses**

In order to demonstrate how each of the four lenses applies to engineering education, we have selected the example scenario where practicing faculty within an engineering program are not

adopting new educational change provided by theoretical research [5, 9, 24]. The contextual interplay in which we apply our theoretical lenses is directly related to types of practice and innovation to emerge [25, 26]. Further, integrating our context of practice and theoretical basis at the outset supports the decision-making processes of individuals working in the field [5, 26]. Thus, this section begins by illustrating the use of each of our four lenses in the context of engineering education. This is followed by demonstrating how the lenses, now tied to engineering education, fit together in a way that broadens the types of potential successful practices and deepens our understanding of pathways to achieve these results.

*User Experience Design*

Garret and others identified a common set of phenomena that affect the design outcomes of those developing user-facing systems [15, 16]. These impactful phenomena, which culminate over time and reduce usability, are summarized as:

- Design by default: The structure of a system relies solely on prior organization technology.
- Design by mimicry: The following of prior conventions regardless of how appropriate they are in the context of a system.
- Design by fiat: The reliance on personal preference instead of on user needs during the design of a system.

A familiar scenario on every campus is the faculty member who continues to give the same lecture every semester until their notes yellow and disintegrate. UXD helps us understand some of the reasons this individual may not wish to change. If they design by default, they are using the organizational technology and infrastructure most easily obtainable in their organization, in this case, the lecturing using notes. If they design by mimicry, they continue to use the notes from when they took the course because the notes worked for them; this would continue to be true even if the context or description of the course changed. If asked, this faculty member would say “we’ve always taught this course this way.” If they design by fiat, they are electing to not update their course because their personal time needs and preferences outweigh the needs of the students. Similarly, we can use this lens to broaden our set of potential reasons why the individual has selected their design method. By observing the scenario through the lens of user experience design, we gain new insights on the potential causes stopping theoretical change from becoming implemented change.

*Complexity Theory*

An observed problem within the field of complexity theory is that if an organization or system is deemed complex, the analysis of elements within the system cannot be individually analyzed or have individual conclusions lead solely to inferences about the larger system. There is a vast amount of information embedded within organizational relationships; reductionist analysis is not compatible with highly interconnected information systems [5]. In addition, organizations of learning contain multiple interconnected elements, experience evolution over time, and consist of members who have different levels of understanding of organizational goals, which easily fits the

criteria of complexity [7]. Through the lens of complexity theory, attention is turned away from the specific tasks implemented by the faculty member, and instead turned to the internal organizational pressures that were apparent during task formation. In our example scenario, the expectations for evaluation and promotion, the norms and culture of the department, and external time demands on the faculty member may be interacting in a way that even an individual that is interested in updating their course elects not to.

*Open Systems Theory*

Open systems share a property of equifinality with complex systems. Equifinality means an organization or system has many flexible patterns for reaching any given end result, with a variety of starting places, resources, or methodologies leading to said results [12]. Open systems on a large scale suggest that the system must organize with the outside environment in mind, but on a smaller scale identifies each component within the open system at its own open system [27]. Components within the system closely or inter-related depend on each other for the sustainment of the system and require a level of "openness," engaging in the same cyclic cycle as the larger system from receiving an input, undergoing transformation, producing outputs, and receiving feedback [12]. The observed problem within open systems is that when this required level "openness" between is not met. When components fail to meet the condition, the adaptability of the system decreases, as the proper control processes cannot be formed by the system to respond to new environmental inputs [27]. Open systems give us an additional perspective on potential barriers to change in the external environment, internal processes (including feeling competent to make the changes), and feedback loops connecting the inputs of content changes and student needs to the outputs of how the course is structured and taught.

*Narrative Analysis*

Narrative Analysis is a specific qualitative emerging research methodology within engineering education [21]. Narrative analysis is particularly suited for the study of education as it focuses on the way people experience life, and education is predominantly a life experience [6]. NA, by capturing a narrative response to a prompt from a sample population, allows for resulting analysis that provides insights on the research question that are initially beyond the surface of the research and into the domains of human behavior [21, 23]. Narrative analysis helps us understand the internal decision-making processes, needs, and the desires of the individual faculty member as well as the students in their course. Once we can describe their experiences as their personal stories, we can look for themes that illustrate both the barriers to change and potential ways to remove the barriers.

## Integrating the Whole

When the four perspective lenses are applied to the scenario of practicing faculty not implementing change supplied by theoretical research, each presents a unique outlook on "change factors" such as:

- How change was resisted within the scenario.
- The location of the interface between the lens and the scenario.

- The overall view of the scenario.

Table 1 provides a summary of these themes across all four lenses.

Even a quick observation of change resistance among the lenses shows a large degree of variance. Change resistance for narrative analysis yields the faculty was unresponsive due to a misalignment of the current and desired experience, while complexity points to a lack of understanding into the organizational relationships/ lack of support. If viewing the scenario through each lens provides differing change factors, how then do we determine the true root cause the scenario and implement corrective measures that create positive change? How do we determine if our problem is a function of complexity or user experience? Each perspective alone cannot provide such insight, but instead a multi-lens framework that simultaneously and cohesively considers each perspective-lens and its scenario influence would be better suited for the task.

When observing the relationships that occur between the perspective lenses, new information begins to emerge. For example, how the interface for narrative analysis takes place on the micro-level between implementing faculty and those who are directly engaged with the implemented change, compared to how open systems interfaces with macro-level internal and external organizational relationships. The mapping the perspective lenses and their change factors is the initial stage towards capturing the inter-related relationships required for creating a cohesive multi-lens framework.

Table 1. Summary of change factors across the four lenses.

| | How is change resisted in the scenario? | Where does the lens interface within the scenario? | Overall Scenario View |
|---|---|---|---|
| Narrative Analysis | Variance in understanding between current experience and desired experience. | Between the faculty member and the students. | Understanding the current context is vital to delivering change provided by research. |
| Complexity Theory | Resisted by lack of support, or lack of understanding into vital organizational relationships | Between the internal pressures applied by the organization and the implementing faculty member. | Internal pressure and key relationships between faculty members organization determine produced change. |
| Open Systems Theory | Lack of understanding between the state of current curriculum and required curriculum | Between the external organization environment, other internal systems, and the faculty member. | Frequent communication and engagement with the other internal open systems is vital for achieving steady state. |
| User Experience Design | Implementing faculty responding to change with design by default, mimicry, or fiat. | Between the process used by faculty to drive change pointed out by theoretical research. | UXD process determines the usability of implemented change. |

## Pathways Forward: Implications and Future Work

What insights can we draw about engineering education research if we diversify our thinking to new research frameworks? What new questions will we be able to study when other sets of perspective lenses our combined together? When it comes to researching education, there are often no simple connections between the findings of our educational research, and the

development of policy to be put in place by practitioners [5]. Two potential attributing factors to the encountered phenomena could be first, the difficulty in research providing change that is easily implementable by practitioners, and second the discretion used by practitioners attempting to implement change failing to resemble the policy called for by research accurately. Each perspective lens (Narrative Analysis, Complexity Theory, Open systems Theory, User Experience Design) shapes how we view what occurs within our institutions.

The environments in which we teach are complex, and open, consisting of many elements that each apply regulatory functions to uphold sustainment of the system. At times we may have a great sense of the organizational objective of our institutions, but there is equal importance in the understanding the user objective if we aim to deliver meaningful change. Approaching the task of research, and the development of practice with a more holistic understanding of our environment, as well as the needs of those who exist within it allow for developments within engineering education improvement that are assets, not liabilities. The mapping of perspective lenses and change factors allows for the capturing of new emergent relationships that will serve was the foundation of a multi-lens framework suited for research within the domain of engineering education.

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