WIP: da Vinci's Cube: Reframing Innovation in ECE Curricula

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Abstract*—This work-in-progress paper reports on a new innovation model that extends Pasteur's Quadrant by adding an axis called Contemplation of Sentiment, which reflects the human-centered aspects of innovation. Human-centered designers and artists have played an integral role in innovation throughout history up to the present day. However, engineering education programs have not often included this integration - relying on a focus on "STEM" even though leaders in industry from Amazon and Apple to Qualcomm and SpaceX have left this exclusionary approach behind. Pasteur's Quadrant is a model adopted by industry and US government agencies to point to the relationship between basic and applied scientific research. To describe the implications of this model, we share the qualitative methodology and early results collected in over 30 individual interviews with thought leaders in industry reacting to da Vinci's Cube. We are exploring the question, "What is the connection between artists, designers, and broad societal innovation in relation to economic and job growth?" Early findings show that managers place themselves, their company, and their hires on relational intersections that include our added axis of "contemplation of sentiment". We discuss these findings in the context of an NSF-RED team that developed a notable exception to the narrow curricula typical of electrical and computer engineering undergraduate programs.

***Keywords*—sentiment, innovation, industry partners in education, arts-integrated research, Pasteur's Quadrant, interdisciplinarity**

I. Introduction

This work-in-progress research paper introduces a tool for understanding and shaping conceptions of innovation both historically and through contemporary practices in engineering education and industry. We extend Pasteur's Quadrant, a model that Stokes used to reframe the false model that dichotomizes basic research intended for expanding our understanding of the world and applied research for solving problems [1]. As shown in Figure 1, Stokes moved from a linear axis connecting basic to applied research to a quadrant of two axes, "quest for knowledge" and "consideration of use." Using the careers of scientists such as Bohr, Edison, and Pasteur, Stokes argued for a new approach of use-inspired fundamental scientific research that would lead to a better understanding of the dynamic interplay between science and technology in which the two overlap and support each other.

We are developing a new model of innovation—"da Vinci's Cube" —that extends Pasteur's Quadrant to include a dimension concerned with emotions, senses, and empathy, which we call "contemplation of sentiment" (Fig. 1). By adding this new dimension, we highlight human-centered design and arts-informed perspectives that are crucial for identifying opportunities for innovation and generating ideas for those opportunities, thus offering a more accurate framework to guide advances in higher education, workforce development, and research design. Note, the axes are not orthogonal – in most cases overlaps exist, and this overlap is enabled in the 3-dimensional model. Our research also includes historical case studies of examples of arts-integrated innovation [3] and visualization of quantitized results. In this work-in-progress paper, we describe the methods being developed to test this model and discuss its relevance in the context of a curricular innovation in electrical and computer engineering department.

II. Methods

A. Research Design

We are using a content analysis approach guided by overarching categories of deductive and inductive themes. Our goal is to develop and test the concept of contemplation of sentiment as a critical component of skillsets needed for innovation in the workforce. Our initial approach was to construct da Vinci's Cube as a conceptual model that we then visualized and iterated with input from user-centered research.

Using this visual, we created a two-part interview protocol in which part one questions ask the participant to reflect on their professional career and part two questions directly point to the da Vinci’s Cube graphic. Data analysis was conducted using

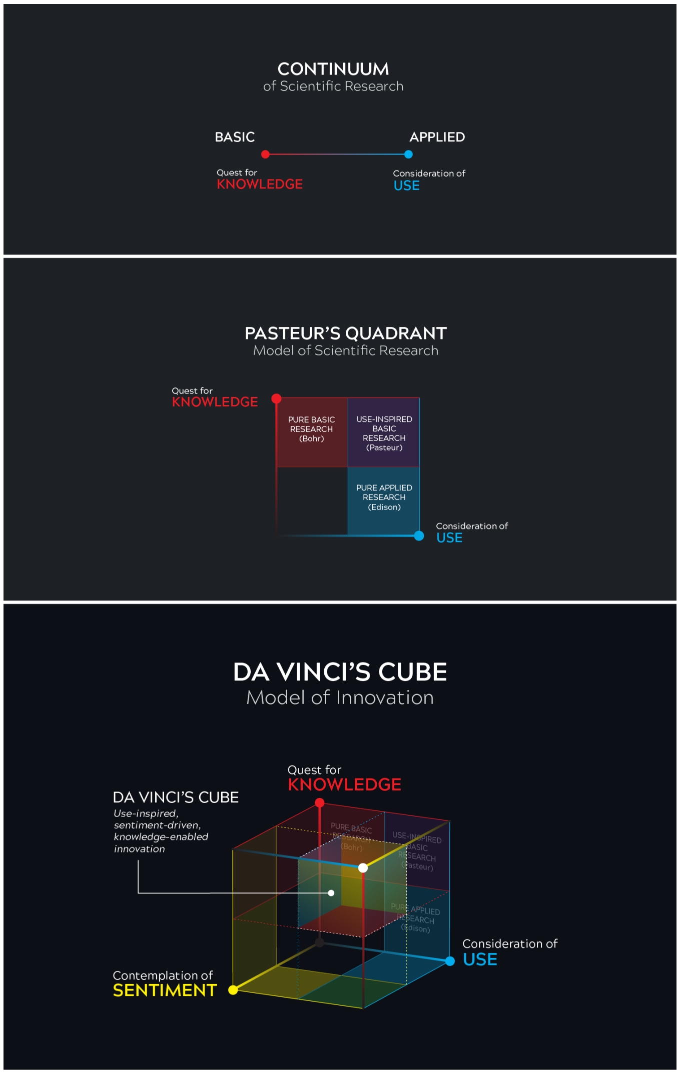

Figure 1. Visual model of extended Pasteur’s Quadrant [2]

both deductive codes derived from the axes of the da Vinci’s Cube and open-ended coding to identify emergent themes. We address the research question, “What is the connection between artists, designers, and broad societal innovation in relation to economic and job growth?”

B. Research Context

Our research team includes students, academic faculty, and professionals working in interdisciplinary institutes and academic settings. Aligned with the example of *Branches of the Same Tree,* a National Academies report on Integrating Higher Education in the Arts, Humanities, Sciences, Engineering, and Medicine [4], we are exploring the value of arts-integrative research, both in academia and in the U.S. workplace. In contrast, however, we are collecting perspectives from business workplaces rather than academia. Our participants are professionals with extensive business backgrounds in innovative industries, companies, and entrepreneurial ventures.

C. Data Collection

Participants were contacted by email and asked to participate in a 45-minute interview conducted online using Zoom. The interview participants were identified through professional relationships, who have connected us with their professional contacts using a “snowball” method. Criteria for selection include 15 or more years of experience working in a professional context that involves innovative creation or application of science or technology (an iconic example would be Apple Inc.). Participants work in a range of roles, including human resources, product development, marketing, and more.

We iteratively developed a semi-structured interview protocol as described above, beginning with questions about the participant and ending with questions specifically about how the participant sees themselves and their company in the space of da Vinci’s Cube. The questions in the first part of the interview are designed to elicit participants’ viewpoints about their personal career trajectory, about the innovative aspects of their company, and about the characteristics of innovative members in the workforce. The second part of the interview begins with the interviewer showing an animated version of da Vinci’s Cube and explaining the logic of adding an axis of contemplation of sentiment. The next set of questions is similar to the first set, with the difference of asking the participant to locate their answers in the space of da Vinci’s Cube. For example, participants are asked, “Where do you see yourself on the axes of the Cube?” By structuring the protocol in this way, we hope to limit any bias from introducing the model before the participant describes their own context.

Interviews were conducted online, audio-recorded, transcribed, and “cleaned” to protect the participants’ personal and professional identities. The resulting transcripts were then added to our atlas.ti account for qualitative analysis.

D. Data Analysis

Since the model we are developing builds on Stokes’ model of Pasteur’s Quadrant, we are using an approach based on this prior model. Accordingly, the initial codebook consisted of deductive codes derived from Stokes’ Quest for Knowledge and Consideration of Use, with our added axis Contemplation of Sentiment. The initial analysis consisted of two researchers coding five interview transcripts using these three concepts as guidelines and discussing patterns with the other three members of the research team. The coders iteratively coded these transcripts, kept notes through a memo process, and reflected with the other researchers who simultaneously were conducting the interviews. After going through this cycle for several weeks, the two coders created a codebook that retained the initial deductive codes and 12 additional codes observed through pattern recognition.

A third researcher was added to the team to help code the remaining interviews using this codebook. The three coders separately coded two transcripts, met to discuss alignments and disagreements, then coded two more transcripts to achieve a high degree of interrater agreement. The researchers analyzed the transcripts in this way, meeting weekly to compare and merge results.

III. RESULTS

Our initial result in this work in progress is a working codebook that was constructed using a content analysis approach guided by overarching categories of deductive themes and inductive themes (Table 1).

Through this process, the team noted that participants usually spoke about innovation in an evolutionary or even transitive manner. For example, most participants would answer the first question about their role in their company chronologically, explaining their roles by reflecting on how they began. Likewise, when asked to place themselves on da Vinci's Cube, they often would state "I used to be here [indicating a location on an axis or in one of the octants] but now I'm here." They would also describe a product or process they were involved in by stating a method, intention, or motivation that led to a result. For example, "We developed a scientific tool for artists to gain more knowledge about their work." We used this pattern to develop subcodes that indicated instances of da Vinci's Cube consisting not just of three categories (Knowledge, Use, Sentiment) but rather relations between different points on the axes. To record these patterns across the dataset, we added three subcodes to each of the initial categories that indicate an output or intention and the method or starting point.

In addition, each coding instance included either stated or unstated context in terms of perspective. To capture this level of detail, we added four codes indicating whether the perspective was about the individual, the organization/company, the audience/customers, and/or a general statement. This level of coding allowed us to note patterns of individuals and their motivations, interpretations of groups of people, and company goals. Initial results using this method show a dominance of consideration of use within an organizational scope. However, when participants describe contexts of audience and personal scope, contemplation of sentiment increases to nearly the same amount.

Table 1. da Vinci's Cube Codebook [6]

	Description	**Example/quote**
Quest for Knowledge	Desire to create/generate knowledge	
Knowledge → Knowledge	Quest for knowledge for its own sake	"Very exploratory"
Use → Knowledge	Consideration of use driven by quest for knowledge	Company creates products used in biomedical research
Sentiment → Knowledge	Generation of sentiment driven by quest for knowledge	Educational materials meant to spark curiosity
Consideration of Use	Consideration of practicality/use	
Use → Use	Generation of use for its own sake	"Very focused on quarterly growth"
Sentiment → Use	Contemplation of sentiment driven by consideration of use	"Use affinity in design to garner repeat sales"
Knowledge → Use	Quest for knowledge driven by consideration of use	"At first a lot of user-centered research"
Contemplation of Sentiment	Consideration of emotional/sentiment impacts	"More like a labor of love than making money"
Sentiment → Sentiment	Generation of sentiment for its own sake	'Art for Art's Sake'
Use → Sentiment	Generation of use driven by contemplation of sentiment	Creating light-sensitive film
Knowledge → Sentiment	Generation of knowledge driven by contemplation of sentiment	Communicate studies of animals in order to make people care about the environment
Scope	Perspective/context	
Individual	Consideration of one's own values/motivations	"It is close to my heart"
Organization	Consideration of operations within an organization	"A merger of cultures, of system, of people"
Audience	Consideration of the audience/users of a product or process	"Curriculum products that physiology educators use"

IV. DISCUSSION

In developing the da Vinci's Cube model, we added a third axis of Contemplation of Sentiment to capture a key piece of innovation. Based on our initial findings, most people do not do their work on the Pasteur's Quadrant back plane of Knowledge and Use; most activities focus in some way on identifying and addressing people's problems, and this requires empathy. With this framework, we argue that educators have the responsibility to create space in the engineering curriculum for students to consider and practice all three dimensions. While many classes begin on the back plane by focusing on Quest for Knowledge and Consideration of Use, many engineering students go into careers that require skills that are along the Contemplation of Sentiment, e.g., the empathy to understand a customer's pain points in developing product requirements.

In this work-in-progress paper, we discuss the implications of da Vinci's Cube through a case study of making room in the curriculum of an undergraduate electrical and computer engineering (ECE) program [5]. The history of the curriculum in this study was one of accretion across history. The department began as an electrical engineering program that grew as that field expanded and also grew by adding the emergent field of computer engineering in the 1980s. The curriculum had not been substantially revised since 1989, when the computer engineering degree was created, and the result was a fractured compilation of electrical engineering (EE) and computer engineering (CPE) faculty and courses. The course requirements for students were mostly discrete. Our project was to unify the curriculum by creating a common core curriculum that taught EE and CPE together in the sophomore year.

Another component of this unification was to create space for students to tailor their course work to fit their own career goals, including defining their own breadth requirement to be made up of courses from outside of ECE. We transformed a curriculum that was siloed into EE and CPE, that had not been updated for decades, and had also accumulated into requirement courses packed into four years that allowed little to no choice for students. Our revision unified the foundational knowledge of EE and CPE in an updated hands-on design sophomore year and created space for students to define their own pathway to an engineering degree, including the possibility of breadth courses outside of ECE yet connected to their career goals.

Now they are allowed to use courses outside ECE for 9 credits that used to be restricted to only ECE credit hours. In the previous curriculum, students used to be able to earn a minor only if they added extra hours. This caused students to either take summer courses or add an additional year to their studies, which restricted the opportunity of attaining a liberal education to students who could afford the extra time and tuition costs. Now all ECE students can choose and complete an interdisciplinary path within existing credit hours that count toward their ECE major.

The curriculum revision required extra care to offer this level of diversity and inclusion. In order to not strand a student, the department strongly encourages students to choose 9 credit hours/3 courses in an established minor that they are registered for, thus ensuring that the courses will be offered and they will be granted entry. The process is also consistent across ECE majors/students: they individually write a justification about their selection including a narrative about how the focus fits into their career goals. This part of the process not only helps them chart their undergraduate path; it also helps them start to create their own professional narrative. The justification uses a standard template so that advisors, who review the narratives with students, are not overwhelmed with additional work. Examples that students have chosen for their secondary focus outside of ECE include real estate, leadership, Chinese, gender studies, math, physics, and computer science.

In addition, students who are interested in topics on the border between traditional EE and CPE are now also able to use ECE courses to create their secondary focus across both degrees, not just within their BS degree. For example, one faculty member in power systems appreciated that students could now take cybersecurity courses, e.g., for preventing cyber attacks on the power grid. In the old program, this was only achievable by getting a BS in both EE and CPE because the two degrees did not have a common core, and thus took much longer. So, with our new common core, an EE student majoring in Power Systems could graduate with a unified foundational knowledge of electrical engineering and computer engineering, thus enabling them to have a secondary focus in Cybersecurity from the CPE program.

In conclusion, if engineering programs want to offer their students opportunities to practice and prepare for real-world careers that require entrepreneurial, innovative, and interdisciplinary skills, they need to make room in their programs to build up their skillsets along the Contemplation of Sentiment axis in the da Vinci's Cube model. When interdisciplinary breadth can be individualized by students themselves, they begin to build their own professional identities through knowledge, use, and sentiment. By reflecting on their own positions across the da Vinci's Cube axes where they are in the Cube now and where they aim to be in the future, they gain agency, and opportunities are opened to extend the diversity, reach and ultimately the impact of engineering education.

V. Conclusion

Pasteur's Quadrant is a model that represents innovation through a framing in which science and technology are interactive and mutually supporting. To expand its applicability in an era where attention to human-centered approaches is increasingly important, we are adding an axis of Contemplation of Sentiment to develop da Vinci's Cube. As a theoretical framework, da Vinci's Cube has potential for characterizing traits of innovation that includes arts-integration in companies and individuals. This work in progress describes initial development of a method to test the model. Beginning with the three constructs of knowledge, use, and sentiment, we are using a deductive and inductive content analysis approach to qualitatively analyze patterns in interviews with leaders in innovative organizations outside of academia. Early patterns indicate that participants interacting with the model predominantly include consideration of use. However, they reflect on their individual and company evolution as including each of the three axes in complementary ways. To demonstrate the usefulness of our model in an ECE educational context, we discuss a case study of a curricular innovation, in which space was created for undergraduates to freely choose electives that count toward their major.

Acknowledgments

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