AC 2012-4004: A SYMPHONY OF DESIGNIETTES EXPLORING THE BOUNDARIES OF DESIGN THINKING IN ENGINEERING EDUCATION

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design theory and methodology, including: (1) research in computer representations to support conceptual design, design for manufacture and assembly, and design retrieval; (2) developing computational representations and tools to support exploration of very complex engineering design spaces; (3) research in solid freeform fabrication, including geometric processing, control, design tools, manufacturing applications; and (4) design and development of energy harvesting systems. Dr. Crawford is co-founder of the DTEACh program, a "Design Technology" program for K-12, and is active on the faculty of the UTeachEngineering program that seeks to educate teachers of high school engineering.

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A Symphony of *Designiettes* – Exploring the Boundaries of Design Thinking in Engineering Education

ABSTRACT

In this paper, we consider the integration of design into engineering curricula from the perspective of *designiettes*. *Designiettes* are glimpses, snapshots, small-scale, short turnaround and well-scoped design problems that provide a significant design experience. While most engineering programs around the world introduce design at distinct points in a curriculum, such as freshman and capstone design courses, we present the concept of a "4-D" design pedagogy, where design is integrated across courses, semesters, years, and extra-curricular activities. This pedagogy, or framework, may be implemented in whole or in part in any engineering program.

Building on this design pedagogy, we present the context of designiettes in terms of educational theories, the I-Engineering, and assessment. We then explore the strategic development and use of designiettes, and present a literature review on small scale design project efforts as they relate to the concept of designiettes. This literature leads to a categorization of characteristics and questions that form a basis for creating designiettes for use in engineering curricula. Exemplar designiettes are then presented to illustrate their development and implementation process.

I. INTRODUCTION

Design in engineering curricula typically entails solving open-ended problems by groups of students over a significant academic time period. These design experiences may include interdisciplinary teams. They may include clients and resources from industry. They may include a distinct focus on design methodology and supporting techniques.

Over the last two decades, a significant movement exists to create more design-centric, or at least problem- and project-based, learning approaches as part of engineering curricula. This movement recognizes the motivational potential of design as a context for learning engineering content, but typically focuses in many ways on the longer-term and iterative aspects of design experiences. A complementary approach, however, is the development of ***designiettes*** within design courses, general engineering course activities, supporting fundamentals courses toward an engineering degree, integrated and coordinated design activities across semester offerings, or outreach activities with the community or K-12 programs. But what is a ***designiette***?

Designiettes, "design vignettes", or "designettes[1]," are glimpses, snapshots, small-scale, short turnaround and well-scoped design problems, or mini design projects, providing a significant design experience, while requiring a minimal amount of time and resources. They are different than hands-on demonstrations in that they ask the student to engage with an ill-defined problem. They are different than an experiment in that they ask students to investigate multiple potential solutions.

Designiettes may be scoped according to time and resource allocation. They may be apportioned to particular technological or project domains, they may be thematic, and they may focus on certain phases of the design process. Ideally designiettes include a need-based project or one that provides a connection to humanitarian issues or the 21st Century Grand Challenges (. Ideally, designiettes include an innovation goal with the process steps of ideation, prototyping, and experimentation. Ideally, designiettes provide a

[1] Designettes is a play off the activity known as a charrette. Charettes are typically associated with urban planning, land use planning, and architecture wherein an intensive collaborative effort of designers is devoted to quickly generate solutions to a design problem.

meaningful experience that will remain indelibly in the long-term memory of the participants thus shaping the ways they see design in our engineered world. Ideally, designiettes provide an educational experience that participants remember, relive with fond memories, and spark future calls to action through engineering design.

Designiettes are rich opportunities for exploring and studying design, at least within a scaled scope and context. They provide opportunities to teach design from many different viewpoints and perspectives. They create opportunities to teach within a constructivist, social constructivist, active learning, interactive collaboration, or hands-on environment. Indeed, they are hands-on, minds-on experiences. Designettes generate opportunities to excite diverse learners of all ages and all backgrounds about innovation processes through exploring the art and science of design.

Designiettes are precursors to inventions. They are initial explorations. They are a means to test the waters and experiment. Importantly, these are confidence-building moments that are much needed in attracting, engaging, and retaining students in engineering education. They produce heightened interest in STEM programs for K - 12 students. They also reinvigorate engineering students during their difficult core engineering science courses. Simply put, they are a means to have fun with design, making design accessible to everyone and also empower those with the passion and talent for design.

In this paper, we explore the strategic development and use of designiettes. The possibilities for creating designiettes are endless and unbounded. We provide thoughts and guidance on selecting and developing projects that address these possibilities. We also present a literature review on small scale design project efforts as they relate to the concept of designiettes. This literature leads to a categorization of characteristics and basic questions for creating designiettes, including a basic methodology, as part of engineering curricula

Four designiettes are then introduced: (1) a competition-based skyscraper design and construction designiette (architecture, structural design, and analytical design modeling); (2) a competition-based, exploratory designiette focusing on the analytical and experimental parametric design of balsa and bass wood glider airplane; (3) a reverse-engineering and parametric-design-based designiette in machine design; and (4) a needs-based mechanimal designiette focusing on experiencing a design process (ideation, concept selection, prototyping, and testing) with robotics type technologies. The skyscraper designiette is then explored in more detail. These designiettes are intended to be integrated in a classroom environment in 45-75 minutes.

II. BACKGROUND AND CONTEXT

As a foundation to exploring designiettes for engineering curricula, we discuss background and needed context for developing designiettes. These foundational elements include a general pedagogical approach to design across undergraduate education, as recently proposed at the Singapore University of Technology and Design (SUTD); pedagogical underpinnings from contemporary educational theories; a focus on innovation skills through a metaphor for engineering education known as the I-Engineer (White, 2011); and a general assessment approach for skills sets as part of engineering education. While these foundational elements may, in part, be found in the broader literature, a summary here provides structure and connections for the development of designiettes.

	ISTD Curriculum	EPD Curriculum Mechanical Devices	EPD Curriculum Electronic Devices	ESD Curriculum	Architecture Curriculum
5th Year Master's					601: Advanced Design & Research Studio* Partner 602: Thesis Preparation 2: IDC Internship* Partner 603: Thesis * Partner
Semester 8	501: Capstone 2* XXX: Advanced ISTD Elective XXX: Technical Application Elective XXX: HASS	501: Capstone 2* XXX: Advanced EPDM Elective XXX: Technical Application Elective XXX: HASS	501: Capstone 2* XXX: Advanced EPDE Elective XXX: Technical Application Elective XXX: HASS	501: Capstone 2* 502: System Dynamics (15.871, 15.874) XXX: Advanced ESD Elective XXX: HASS	501:Capstone 2* Partner 502: Thesis Preparation* Partner XXX: Advanced ASD Elective XXX: Advanced ASD Elective * Partner
Semester 7	401: Capstone 1* 402: Database Systems * 403: Application Project Course XXX: HASS	401: Capstone 1 * XXX: Advanced EPDM Elective XXX: Technical Application Elective XXX: HASS	401: Capstone 1 * XXX: Advanced EPDE Elective XXX: Technical Application Elective XXX: HASS	401: Capstone 1* 402: Flexibility in Engineering Design (1.146) 403: Project Management XXX: HASS	401: Capstone 1* 402: Integrated Building Systems (MIT 4.464) 403: Computation Elective (MIT 4.512) 404: Alternative Practice- Emergent Design Technologies*
Semester 6	301: User Interface Design & Implementation* 302: Machine Learning* XXX: Advanced ISTD Elective XXX: HASS	301: Dynamics (MIT 2.003, 16.07) 302:Thermal Systems for Power & Environment XXX: Advanced EPDM Elective XXX: HASS	301: Digital Systems Laboratory (MIT 6.111) 302: Microelectronic Circuits & Devices (6.012) 303: Design & Fabrication of Microelectromechanical Systems (6.717) XXX: HASS	301: Network Modeling of Complex Systems* 302: Systems Architecture (ESD 34) XXX: Technical Application Elective XXX: HASS	301: Architecture Design Core 3 (MIT 4.143) 302: Architectural Energy & Water Systems* 303: Building Information Design & Modeling* 304: The Built Environment and Value*
Semester 5	201: Elements of Software Construction (MIT 6.005) 202: Introduction to Algorithms (MIT 6.006) 203: Computer System Engineering (MIT 6.033) XXX: HASS	201:Fluid Mechanics* 202: Engineering Design and Project* Engineering (2 Modules, 16.862, 6.902)) 203: Feedback Control * XXX: HASS	201: Product Engineering & Design (16.862) 202: Electromagnetics & Applications (6.013) 203: Feedback Control * XXX: HASS	201: Applied Statistics (MIT 15.075) 202: Discrete Event Simulation* Partner XXX: Technical Application Elective XXX: HASS	201: Architecture Core Studio 2 (MIT 4.144) 202: Architectural Structure & Enclosure Design* 203: Design & Fabrication (MIT 4.510) 204: Theory & Culture 2 (MIT 4.607)
Semester 4	101: Introduction to Probability & Statistics* 102: Introduction to Information Systems & Programming* 103: Computation Structures (MIT 6.004) XXX: HASS	101: Introduction to Probability & Statistics* 102: Signals & Systems (2.004, 6.003) 103: Structures & Materials 2.001, 2.002) XXX: HASS	101: Introduction to Probability & Statistics* 102: Signals & Systems (2.004, 6.003) 103: Circuits & Electronics (6.002) XXX: HASS	101: Introduction to Engineering Systems* 102: Applied Probability for Engineering Systems (MIT 6.041) 103: Optimization (MIT 15.053 &15.093) XXX: HASS	101: Architecture Core Studio 1 (MIT 4.143) 102: Architecture Science & Technology (MIT 4.461) 103: Introduction to Rule Based CAD Modeling & Design* 104: Theory & Culture 1 (MIT 4.605)

Freshmore Year

Semester 3	• SOPH 301: Modeling the Systems World • SOPH 302: Engineering in the Physical World • SOPH 303: The Digital World • SOPH 304: Introduction to Biology
Semester 2	• MATH 201: Advanced Math II • PHYS 201: Physics II • TECH 201 : Introduction to Design • HASS 201: World Civilizations and Texts II
Semester 1	• MATH 101: Advanced Math I • PHYS 101 : Physics I • CHEM 101: Chemistry- From Atoms to Crystals • HASS 101: World Civilizations and Texts I

Figure 1. SUTD curriculum and pillar structure (www.sutd.edu.sg)

Design, as an academic discipline, cuts across all curricula (Fig. 1) at SUTD and will be the framework for novel research and educational programs. SUTD has been founded on the belief that technology and design are essential to the world's well being and progress. Ever since the dawn of the human race, design and technology have been the forerunner of countless new discoveries. With creatively designed machinery that is unsurpassed in speed and efficiency, novel inventions have sprouted all over the globe. Indeed, possibilities are endless in a day and age where information is rampant and new designs and discoveries are shared the moment they emerge.

This view of design at SUTD is referred to as the "Big D." Big D includes architectural design, product design, software design, systems design and basically all technically grounded design. It is design through conception, development, prototyping, manufacturing, operation, and maintenance – the full value chain. It includes an understanding of the liberal arts, humanities, and social sciences. In short, Big D encompasses the art and science of design.

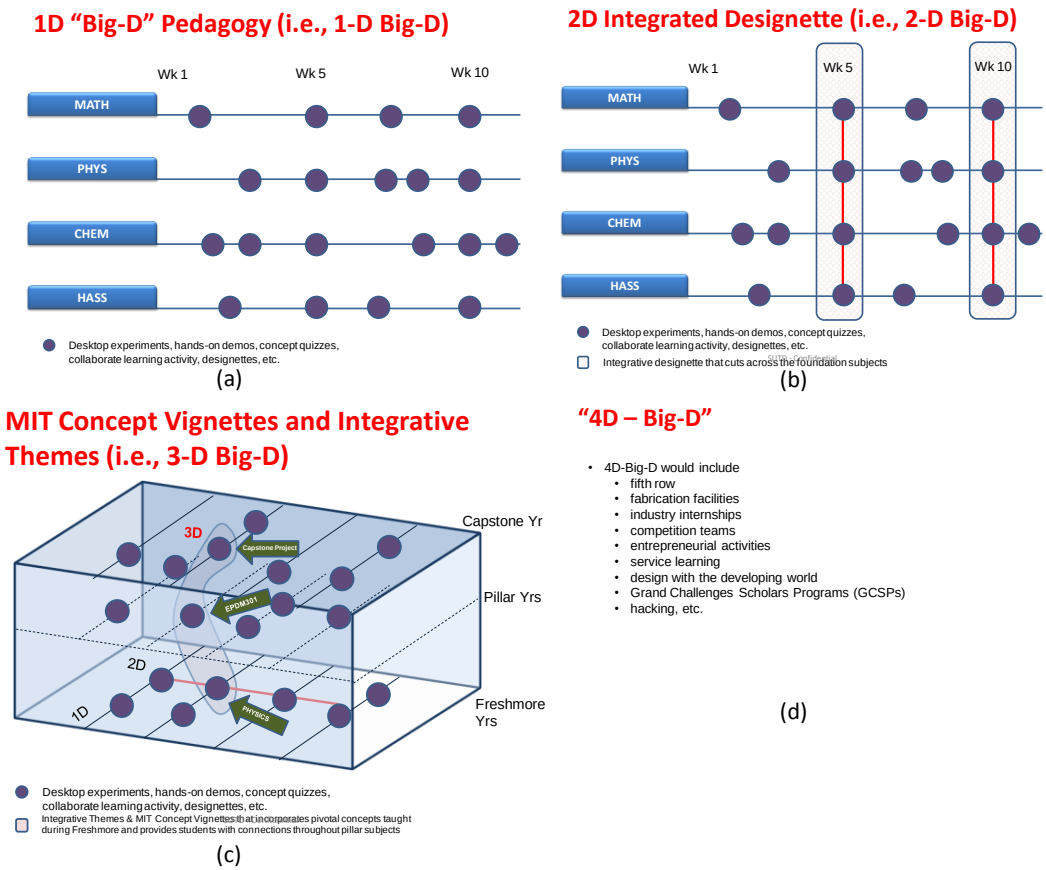


Figure 2. Proposed 4D Big-D pedagogy, integrating designiettes into engineering curricula

As part of this Big D design focus, SUTD is considering a proposed, novel pedagogy for integrating design throughout the curriculum. This pedagogy, or framework, is known as the "4D" Design Pedagogy, where "4D" refers to four dimensions. Figure 2 illustrates this pedagogy, in each of its dimensions, for the first semester of the freshmore year at SUTD and beyond. Figure 2a integrates designiettes and other active-learning exercises at the individual course level. Figure 2b integrates designiettes across courses in a given semester through the introduction of more extensive designiettes at key points in a semester, such as weeks 5 and 10, where the designiette is carefully created and scoped to utilize the content across courses. Figure 2c shows the 3D nature of the pedagogy, where design crosses and integrates across the years of the curricula through concept vignettes and themes introduced during the invocation of a student cohort and encountered through the last-year multi-disciplinary capstone experience. Concept Vignettes provide a broar umbrella by which we may develop innovative educational approaches to capturing, archiving, and projecting pivotal concepts in support of and in collaboration with teaching faculty. A Concept Vignette may be embodied through video media, but it also may be embodied in many other forms, such as artistic renderings, poetic verse, writings, etc. Figure 2d illustrates the fourth dimension of the 4D Big-D pedagogy. The fourth dimension cannot be readily visualized, but instead embodies the extra-curricular and outside the classroom activities that are strategically developed and coordinated to enrich design in the students' experiences.

II.2 Pedagogical Underpinnings

Engineering education continues to change as we encounter more interdisciplinary learning and create access for a wider variety of students to join the college classrooms (Adams, et al., 2004; Anderson & Northwood, 2002). In better understanding the intricacies of student's learning, educators can improve the

teaching of engineering concepts. One of the keys to the effectiveness of introducing designiettes into engineering curricula will be their foundation in prominent learning theories. A variety of salient educational theories guide the creation, assessment, and improvement of designiettes, within an active-learning context. These learning theories range from how information is presented and processed to understanding an individual student's personality and preferences. Four of these theories are described below and may be central to the development of designiettes and their associated design, implementation, and assessment. Other theories may also contribute significantly including multiple literacies, inductive/deductive presentation, Scaffolding, and Novak's model of learning.

Learning Experience Progression: Kolb Cycle. The Kolb model shown in Fig. 3 describes an entire cycle around which a learning experience progresses. The goal, therefore, is to structure learning activities that will proceed completely around this cycle, providing the maximum opportunity for full comprehension. This model has been used extensively to evaluate and enhance engineering teaching. The designiettes may be designed to provide learning experiences in the Kolb cycle that are not well met with traditional course instruction. Specifically, each designiette may be based on actual engineering and need-based problems. This provides the "Concrete Experience" part of the cycle in a similar manner as a case study. The "Reflective Observation" part of the cycle is accomplished by asking questions throughout the designiette which may be designed to encourage the students to reflect on the innovation history, processes, problem, ideas, and / or decisions. The "Abstract Hypothesis and Conceptualization" part of the Kolb cycle is accomplished by the use of the course content itself, in addition to supporting conceptual course material. Finally, the "Active Experimentation" part of the cycle may be met when the students will be asked to interact with hardware, prototypes, and / or simulations.

Figure 3. Kolb cycle for learning experience progression

Active Learning, Interactive Engagement, & Constructivist Theories. Active learning approaches improve students' overall learning, a view shared generally by faculty teaching engineering education (Aglan, 1996). A recent survey of 67 instructors from 59 different US universities, completed by the PIs, indicated that 90% of them would like to include more active learning in their classes. Approximately 80% of these same instructors indicated that the active learning approaches as part of previous NSF projects carried out by the PIs enhance or would enhance their teaching. There is considerable literature that addresses the advantages of using active learning in STEM curriculum (Aglan, 1996; Bonwell; Dennis, 2001; Eder, 2001; Hsi, 1995; Holzer, 2000; Linsey, 2006, 2007, 2009; Mayer, 2002; Meyer, 1994; Prince, 2004; Stice, 1987; Talley, 2007; Welsh, 2007; Wood, 2000, 2001, 2002, 2004; Barr, 2000; Bean, 2001). Students' motivation and learning are simultaneously enhanced by the incorporation of active learning into the classroom.

The foundation of active learning is a constructivist teaching philosophy and, in particular, social constructivism. Through the interaction with ideas, concepts, materials, and other artifacts, students construct their knowledge. This approach seeks to alter the mode of knowledge and conceptual understanding through student construction as opposed to passive reception. Modules may be framed within a constructivist framework in an effort to create engineering education experiences that (1) help students to construct deeper understanding of theoretical concepts in connection to practical experiences; (2) facilitate students' engineering skills; and (3) develop students' capabilities and dispositions for engaging in collaborative project-based inquiry and critical thinking. To assimilate new information and incorporate it into the existing knowledge, students need to restructure their knowledge for themselves which can be accomplished through active learning.

A number of tenants underlie this teaching philosophy, including (Knight, 2004)

- Students take direct responsibility for their knowledge, proactively engaging in the study of their texts and reference materials, participation and leadership in course activities, completing assignments, laboratories, and exploration in the field.
- The instructor assumes more of a role of a facilitator: "a guide on the side, not a sage on the stage" (Knight, 2004).
- Students receive immediate feedback and guidance on their work and class contributions.
- Students invest and spend a significant portion of class time engaged in concrete experiences (doing) and reflections, contemplation and critically thinking, and discussing the topic area of the course. This approach is opposed to a passive listening of the topic from others.

Active learning or interactive engagement does not comprise a single approach but many approaches may be executed through a variety of modes and media. Exemplar delivery modes, with extensive testing (e.g., in the area of STEM physics (Laws, 1997)), include Cooperative Groups (Heller, 1992a, 1992b), Socratic Dialogue Inducing Labs (Hake, 1987, 1992), Interactive Demonstrations (Sokoloff, 1997), Peer Instruction (Mazur, 1997), Think/Pair/Share (Van Heuvelen, 1999), Tutorials (McDermott, 1994, 1998), and Hands-on Activities (Linsey, 2006, 2007, 2009).

Extensive empirical studies have been carried out to understand the role of active learning. Clear evidence exists that the lecture mode of instruction and passive reception by students is not effective at leading to student understanding. Many contributory factors explain this result (Knight, 2004):

- Students are not good listeners in a passive instructional setting. They simply do not know how to listen.
- Critical thinking skills cannot be developed or applied to subject matter due to the pace of content presentation.
- The meaningful attention span of individuals is 10-15 minutes.
- Many orally delivered lectures simply reiterate material in the text or references for a course or topic area.
- Lectures typically focus on abstractions not concrete experiences with a subject matter.

In the area of STEM physics, extensive testing between conventional teaching versus active learning modes showed more than a two times (100%) improvement regarding the conceptual understanding of students with a Newtonian Force Concept Inventory. These results are striking and correlated closely with students' abilities to develop and employ good problem solving skills (Hake, 1998). Depending on one's teaching styles, the intent is to integrate interactive engagement throughout innovative initiatives in courses and the cultural setting of the students' educational environment.

Bloom's Revised Taxonomy. Bloom's taxonomy (Fig. 4) gives six levels at which learning can occur (Bloom, 1956; Krathwohl, 1964; Terry, 1993; Andersin, 2001). This taxonomy is a multi-tiered model of classifying thinking according to six cognitive levels of complexity. In general, a higher level corresponds to a more advanced or mature learning process. Thus, we aspire to focus our instruction in higher

education toward the higher levels. The figure below illustrates the basic elements of Bloom's revised taxonomy.

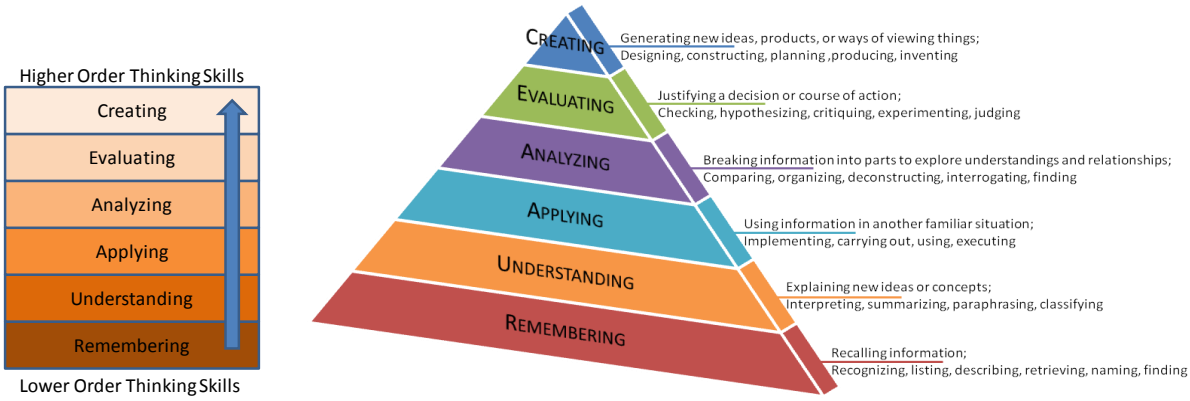


Figure 4. Bloom's Revised Taxonomy of Thinking Skills

Boom's Taxonomy is realized through a number of pedagogical models. In *How People Learn: Brain, Mind, Experience, and School* (HPL), for example, Bransford, Brown, and Cocking argue that the role of educators is to give students "the intellectual tools and learning strategies" that will allow them to grapple with difficult questions and to "think productively" (Bransford, 2000). The HPL pedagogical model suggests that students do not flourish intellectually in classes that simply require them to remember and repeat information. Instead, students benefit most from moving through a cycle that advances them from a stage of merely acquiring information to more advanced stages in which they learn to analyze information and ultimately to synthesize information and apply what they've learned in different situations. Bloom's revised taxonomy, as implemented through Bransford et al.'s model and others, may be utilized as an integral foundation of advancements in innovation content throughout curriculum development.

Five Factor Model (Big Five Personality Dimensions). "Personality is that pattern of characteristic thoughts, feelings, and behaviors that distinguishes one person from another and that persists over time and situation" (Phares, 1991). According to Random House Dictionary, personality is "the sum total of the physical, mental, emotional, and social characteristics of an individual," or "the organized pattern of behavioral characteristics of the individual." Elements of personality include biologically based and learnt behavior which forms a person's unique responses to environmental stimuli (Ryckman, 1982).

There exist a number of theories and taxonomies that attempt to describe and represent personality in individuals. Based on significant research, a commonly accepted theory of personality in psychology is known as the Five Factor Model (FFM), Table 1. Within FFM, there exist five dimensions that describe cognitive, affective and social behavior. These five dimensions include: extraversion, openness to experience, agreeableness, conscientiousness, and emotional stability. The table below lists these five dimensions, their ranges, and their polar traits. Figure 5 shows these dimensions and an exemplar relational plot of two of the dimensions.

Table 1. Personality dimensions and polar traits (Costa, 1992)

Personality Dimension	***Low level***	***High level***
Extraversion	Shy, Withdrawn	Outgoing, Energetic
Openness to experience	Cautious, Conservative	Inventive, Curious
Agreeableness	Competitive, Outspoken	Friendly, Compassionate
Conscientiousness	Easy-going, Careless	Efficient, Organized
Emotional (Neuroticism)	Secure, Confident, Calm	Sensitive, Anxious

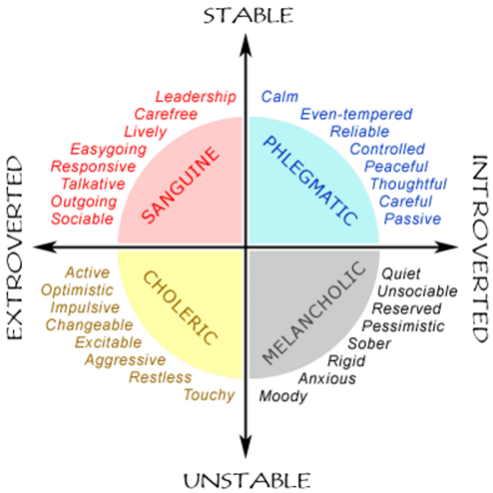


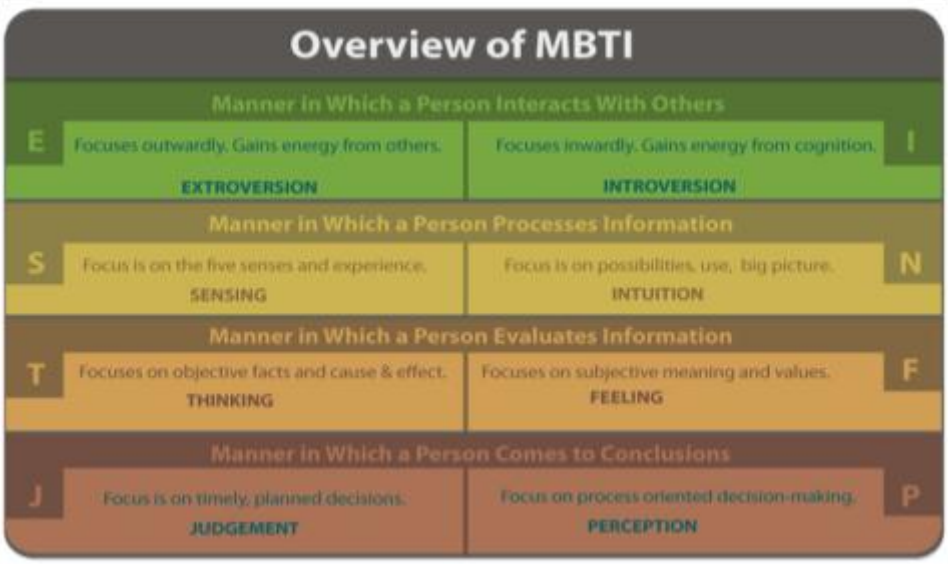
Figure 5. Five Factor Model (http://intraspec.ca/images/eysenck.gif)

There exist a number of other dimensional measures of personality, such as Webster and Kruglanski's "Need for Closure" scale (Webster, 1994). These dimensional measures, e.g., Webster and Kruglanski's, are known to be related to the Five Factor Model. One well known dimensional measure is The Myers-Briggs Type Indicator (MBTI), Table 2. While it is acknowledged that MBTI is not universally accepted in psychology, MBTI has been used for team formation and other strategies in engineering education. It is has also been shown that MBTI is a transformation of the Big Five personality dimensions (McRae and Costa, 1989). Using it in this context, MBTI, as shown in the table below, includes four categories of preferences (extroversion/ introversion, sensing/intuition, thinking/feeling, judgment/perception) that are used to understand and evaluate student personality types. The second of the four categories (sensing/intuition) provides insight into how a person processes information. Those who prefer to use their five senses to process the information (sensors) are contrasted with those who view the intake of information in light of either its place in an overarching theory or its future use (intuitors). This sensor vs. intuitor category is seen by some researchers to be the most important of the four categories in terms of learning implications.

We may design and use designiettes in ways that will be effective for students with different Big Five personality dimensions which we will cast also in the MBTI personality types for purposes of comparison. For example, designiettes may be used in a deductive manner where theory is discussed first and then concrete experiences are implemented. This is beneficial for the intuitors as they prefer to contemplate theory and then move to application of that theory. The designiettes may also have content explicitly addressed to the sensor types. In particular, the tremendous visual aspects of graphics and hands-on manipulables appeal to the sensors. Personality dimensions, under the understanding and

umbrella of the Five Factor Model but also cast as MBTI preferences, may be an integral part of our assessment strategy.

Table 2. Myers-Briggs Type Indicator (MBTI) categories of personality types



*II.3 The **I**-Engineer (White, 2011)*

Imagine the **I**-shaped engineer whose strength is built on **I**nterdisciplinary connections. **I**-beams are **I**ntegral parts of sustainable, strong structural designs because of the **I**nteractions between the parallel flanges and connecting web. In recent engineering education discourse, there is vast discussion of the T-shaped engineer[2] to provide a metaphor for describing an **I**deal engineer: broadly learning and weaving across disciplines (top of the T) and going deeply into understanding engineering concepts (vertical branch of the T). We consider a new metaphor in response to the T-shaped engineer that is **I**nspired by the unique strengths of the **I**-beam to share a vision of an **I**-shaped engineer (Fig. 6). Through **I**nterdisciplinary engineering education, designiette approaches to engineering education will facilitate learning experiences that (a) contextualize design and entrepreneurship within local, national, and global economies, (b) integrate engineering and technical innovation skills, and (c) relate to humanities and policies prompting individual and collective action. With the sustainable strength of this approach to engineering education, **I**-shaped students are able to understand and integrate *viability*, *feasibility*, and *desirability* into design that translates into successful ***I**nnovation*.

Incorporating this new metaphor of the **I**-shaped engineer is an **I**mportant and hopefully **I**nteresting way to **I**nspire the vision for **I**ntegrating designiettes into engineering curricula. **I**deally, designiettes will **I**mprove ways to build culturally- and socially-relevant design and service learning into engineering education and develop **I**nterdisciplinary **I**-engineers and **I**nnovators that choose to face design projects, entrepreneurial endeavors, and the Grand Challenges with vigor and dedication for years to come.

[2] Oskam, I.F. (2009). "T-shaped engineers for interdisciplinary innovation: an attractive perspective for young people and a must for innovative organizations." *SEFI (European Society of Engineering Education) Annual Conference*. Rotterdam (The Netherlands).

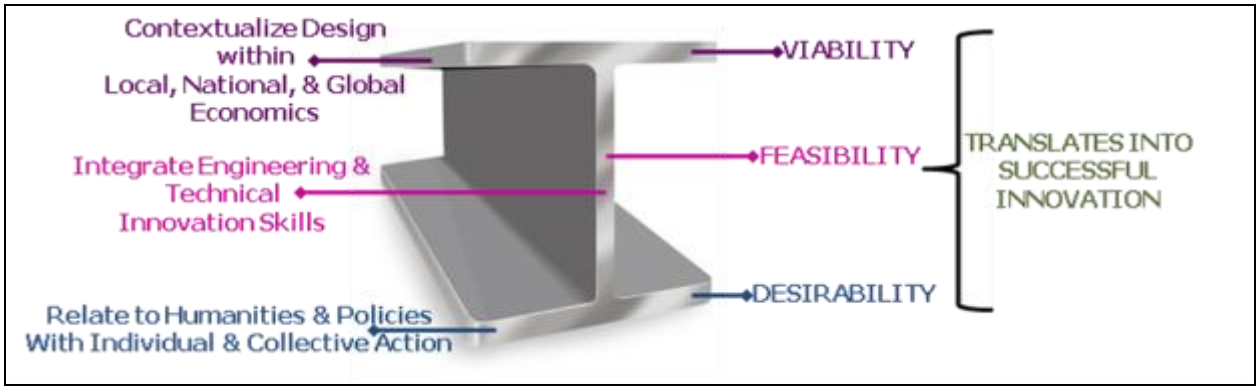


Figure 6. Interdisciplinary Strengths of the I-Engineer (White, 2011)

II.4 Designiettes Assessment and Evaluation: Innovation Mindset and Skill Set

The assessment and evaluation strategy shown in Fig. 7 depicts a general approach to assessing and evaluating the use of designiettes across engineering curricula, from the course level to the program level. The assessment strategy focuses here on the innovative mindset and skills of students, and involves obtaining assessment data from both instructors and students. The strategy, applied both at the formative and summative levels, is to acquire demographic data that can be correlated with assessment from participants. This correlation is created in order to determine if the advancements in designiettes are effective across different demographic categories, in terms of a chosen skill set such as innovation skills. For example, correlations can be made to answer if designiettes are effective across different underrepresented groups or Five Factor Model personality dimensions. An assortment of assessment instruments may be used to evaluate the use of designiettes, including surveys, quick quizzes given before and after a treatment (exposure to a designiette in a content area), exam questions, projects, portfolios, focus groups and concept inventories. This multifaceted approach, using a variety of assessment instruments, we believe, provides a much more comprehensive evaluation of design-based learning than would be possible with a single set of assessment instruments.

Considering designiettes in the context of innovation skills, as assessment plan might with five overarching sets of learning outcomes essential for students, within collaborative team or cohort-classroom settings, to develop an innovative mindset and skill set:

- *Learning Outcome Set 1*: Ideation, concept generation, abstraction, and multiple representations. These outcomes focus on divergent thinking and expansive alternative generation, i.e., enlarging sets of representations students use to generate a larger number of high quality, novel alternatives.
- *Learning Outcome Set 2*: Opportunity and needs analysis. These outcomes focus on analyzing need and context. Bringing results to market requires understanding elements influencing reception, the user (e.g., customer needs and empathic lead user analyses), evolving technologies (competitive environment, technology forecasting, prior art), product context, and financial feasibility.
- *Learning Outcome Set 3*: Quantitative decision making for open-ended, design problems. These outcomes focus on convergent thinking and alternative prioritization. They include outcomes of traditional engineering science courses but within open-ended problem settings.

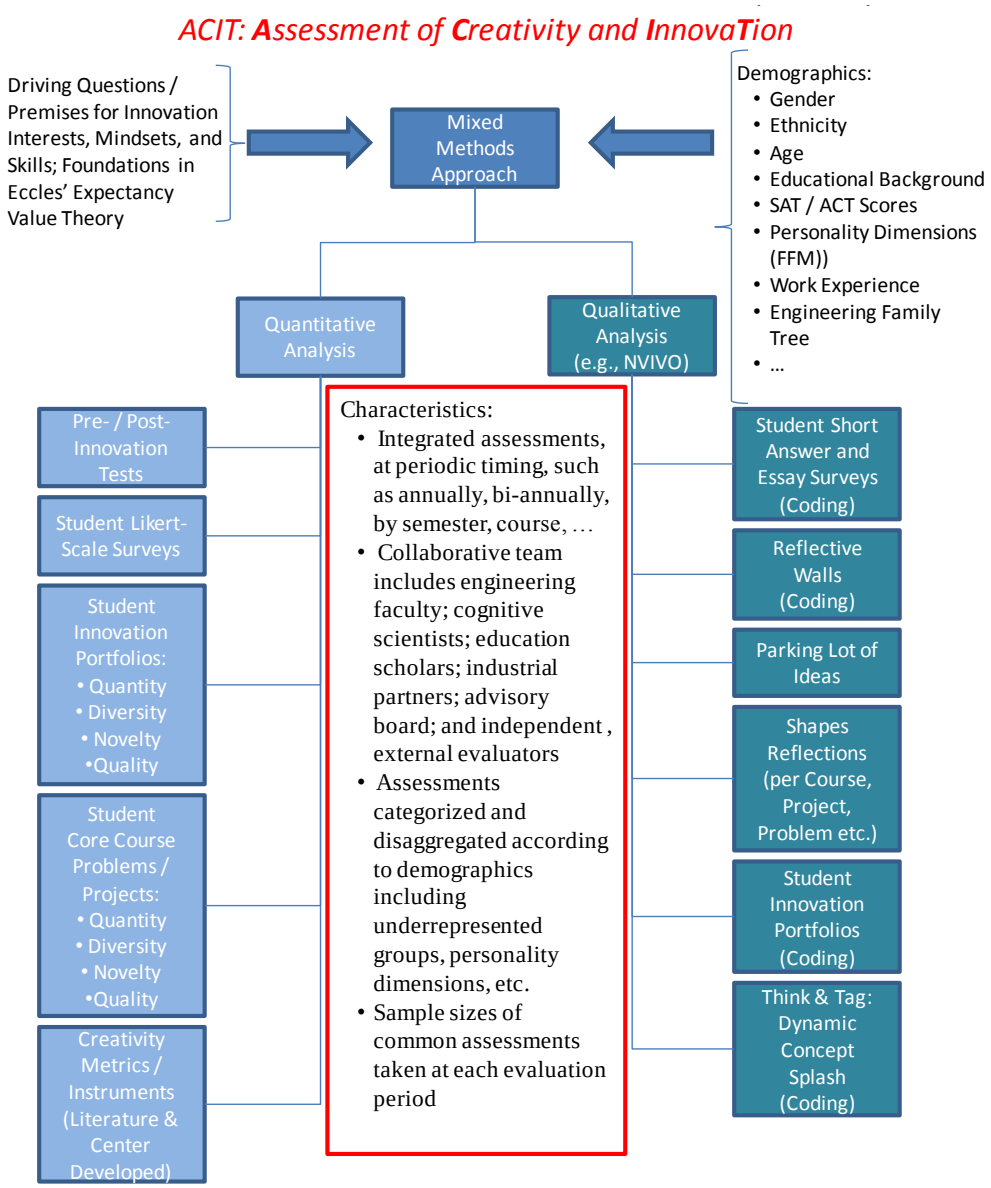


Figure 7. Assessment of Creativity and InnovaTion (ACIT): a mixed methods approach

- *Learning Outcome Set 4*: Creative resource utilization. These outcomes emphasize a different dimension of innovation – resource use for product (or process) realization – to celebrate uses for limited or unused resources. Development of creative resource utilization can be enhanced under various situations: overcoming difficult design constraints (e.g., design of toys to satisfy global environmental and safety constraints), limited resources (e.g., design for extreme affordability, reusing, recycling), alternative uses of existing designs, creative balance of social acceptance of a product and sustainability (e.g. vehicles using clean energy while being attractive to the public). Creative resource utilization is crucial for sustainable development.
- *Learning Outcome Set 5*: Reflection, observation and hypothesizing. Reflective practice is essential to excellence (Schon, 1983). These outcomes emphasize developing abilities to address personal responsibility for identifying societal needs and synthesizing inventive problem formulations as well as developing capacities for reflecting for personal and professional growth.

Innovation skill sets have not been clearly identified or thoroughly studied in the literature. Although categorized into five distinct sets, we recognize overlap, synergy, and concurrent development. All five learning outcomes seek improving abilities of students to work within and lead teams as an important emphasis of designiettes (Froyd et al., 2006; Froyd, Srinivasa, Maxwell, Conkey, & Shryock, 2005; Jensen & Wood, 2000; Jensen, Wood, & Wood, 2003; Linsey, Talley, White, Jensen, & Wood, 2009; Otto & Wood, 1998; Wood, 2001). These learning outcomes sets and associated assessment strategy focus on using designiettes as a key approach to developing I-Engineers. Similar and complementary learning outcomes may be developed to focus on particular subject matter.

III. Literature Review

With fast changing requirements of engineering education and skills desired in industry, universities around the world are making substantial changes to their curriculum and delivery means. One key objective that is seen critical in this regard is the dynamic integration of design into the university curriculum while offering an exciting design immersion to the students. A wide range of design literature in engineering education informs our understanding of design thinking and the integration of design in engineering curricula (Dym, et al., 2005; Wood, et al., 2001; Dutson, 1997; Otto & Wood, 1998; Bilen, et al., 2002; Blessing, 2002; Crawford, et al., 1994; Otto & Wood, 2001). The particular literature review presented here considers examples of courses across engineering, architecture and the arts and humanities that offer design experiences to students through weeks/days-long small scale projects.

One freshman level course that introduces engineering design through small scale projects is the 'ENES 100 Introduction to Engineering Design' sponsored by NSF ECSEL program at University of Maryland at College Park which is taken by nearly 750 freshmen engineering students every year. The course adopts a project-driven approach to replicate three essential phases in the product development process, namely, design, manufacturing and assembly. The students acquire a conceptual understanding of the engineering design process through an active learning experience. Some products developed in the course includes solar desalinization stills, porch glider, wind generator, swing set and a see saw. The freshman design course meets three times per week for a total of 5-hours (Dally, et al., 1993; Calabro, et al., 2008).

At Arizona State University, the Freshman Integrated Program in Engineering (FIPE) sponsored by Foundation Coalition adopts small scale projects to integrate engineering, calculus, physics, and English in the freshman year. The course involves three small scale projects involving construction of a catapult, bungee-drop apparatus and a trebuchet, each over a period of four to five weeks. The level of difficulty in projects increases with time to keep in pace with the student's knowledge of science and engineering. The course enabled the students to appreciate the relationship between all the four disciplines (Roedel, et al., 1995).

Consider the course in 'Mechanical Dissection' created by Sheppard at Stanford with NSF Synthesis Coalition sponsorship. This course consists of a series of small scale projects involving disassembling and reassembling of engineering artifacts. The course aims to offer students an understanding of mechanical artifacts, awareness of design process, power of clear, concise communication and resourcefulness and problem solving skills. The course involve dissection of four different artifacts, one individually and the other three in groups. Some artifacts analyzed include a printer, fishing reel, ten-speed bicycle and an artifact of choice. The duration of the projects ranged from few hours to three weeks (Sheppard, 1992).

The Product and Process Engineering Laboratory course at North Carolina State uses small scale design projects wherein students play the roles of user, assembler and engineer in series as they explore every day engineering products. The course aims to instill early student responsibility and involvement as an engineer, not only leading to enhanced student competence and confidence but also offers them the

pleasure of learning by oneself in teams. Students spent three days and some of the products studied in the course include bar code, photocopier, water purifier and optical fibers (Beaudoin and Ollis, 1995).

The Integrated Teaching and Learning Laboratory course at University of Colorado offers students need based small scale design projects that integrate engineering theory with real life current engineering design problems. The students in a group of four to six per team design assistive technology solutions for clients from the community over a period of six weeks and some of these projects have made a significant difference in the way the client interact with the world. Some projects designed in the course include wheel chair tray, two axis swat switch, door opener and light box (Piket-May and Avery, 1996).

The Introduction to Engineering Design course at University of Wisconsin – Madison uses small scale design projects involving virtual epistemic games to equip students with skills targeting design trade-off decisions, client conflict management, and justification of design choices. The students form teams in group of five each and take 11 hours to complete the project. In the project, the student assumes role of an early career hires in a fictional company and design a next generation dialyzer unit while working closely with a collection of actual and virtual players (Chesler, et al., 2011).

At University of British Columbia, the 'Film Boot Camp' project presents an effective model of how urban youth identify their strength and weaknesses in a rural setup within the context of film making. The students are expected to produce a short in a period of one week working closely in small groups with the mentorship of professional film makers. They are exposed to an environment of cooperative, collaborative and creative practice, reflecting the realities of the film industry. Being a residential program held in a rural island, the territorial bound communities are absent and the students build new relationships and identities quickly (Lin, et al., 2011).

The 'Civil Engineering Materials' course at Lawrence Technological University adopts small scale design projects to introduce incoming students to engineering analysis and basic elements of design. The projects involve real life design challenges wherein students to specify appropriate testing conditions and variables for individual experimental test programs of civil engineering material behavior. Some experimental programs studied include analysis of bond strength of composite and conventional concrete reinforcing materials and comparing wood truss connection assemblies. The projects are done individually or in small groups over a period of 6 hours (Hansen, 1999).

At Kettering University, the sophomore-level 'Introduction to Design' course uses three small scale design projects to offer students a 'real' practice of engineering knowledge and master the processes and tools of engineering design. The first project focuses on the concept of design creativity and engineering communication where the students conceive the internal mechanism of an electro-mechanical device and the second one on reverse engineering analysis on the device used for the first project. Finally, in the third project students manufacture a device pre-designed by the faculty (Tavakoli and Mariappan, 2000).

The 'Introduction to Engineering Design' at Penn State University-Altoona College uses a series of small scale design projects to teach engineering approach to problem solving with an emphasis on team work, communication, creativity, ingenuity, and computer aided design tools. Some of the projects designed include construction of timing and wave shaping circuits, counters, control system for lumber cutting machine and simple chemical process control system. All mini-projects were conducted in small groups (Anwar, 2004).

At US Air Force Academy and The University of Texas-Austin, the small scale design projects in the form of mechanical breadboards are used to establish relationship between machine design principles and the reality of machine components. The mechanical breadboard which consists of a basic building blocks and supporting structures are used in the course to incrementally build a system as the designs of the subsystems are being optimized. The course uses mixture of RC car kits or Lego-Robolab kits with in-class product examples, show-and-tell products and reverse engineering of products for the project (Wood, et al., 2005).

Another example is the 'Introduction to Aerospace Engineering and Design' at MIT where competitive small scale design project is used to introduce real world engineering practice to students in early stages of their undergraduate curriculum. The students form teams of five to six students to design and construct radio controlled blimps capable of carrying maximum amount of payload in a minimum amount of flying time. The design dimension of the friendly competition offers students enormous opportunities to showcase their creativity and ingenuity in designing flight vehicles (Newman and Amir, 2001).

IV. Characteristics, Questions, & Methodology for Creating Designiettes

The sample of literature scenarios in Section III clearly showcase the benefits of weeks/days-long small scale design projects in offering students a rich design experience while fusing design in traditional courses of engineering, architecture, arts and humanities. These design projects significantly contribute to the essential traits of a design engineer as listed in (Sheppard and Jenison, 1997) and innovation skills as discussed in Section II. Based on the literature scenarios, we derive a set of ten (10) basic characteristics of a small scale design project that are needed for successful implementation, integration and delivery of design into the curriculum in a meaningful and interesting fashion. Table 3 lists essential, basic characteristics for a successful designiette, where one, a set, or all of these characteristics may be chosen for the creation of a given designiette.

Table 3. Basic Characteristics of a Small Scale Design Project (Designiette)

Designiette Characteristics
1. Clearly stated learning objectives and learning outcomes within a subject area (science, engineering science, mathematics, humanities, arts, social sciences), within a design process, or within a skill set
2. Intrinsically motivating, interesting, and fun activity
3. Open-ended activity with no single "correct" answer
4. Innovation focus
5. Need-based, well scoped, empowering, and motivating problem
6. Opportunities to ideate, explore design variables, explore the aesthetic, theme, explore economic or policy issues, explore ergonomic features, or some combination
7. Prototyping of ideas, at least virtually as part of a simulation, or physically as a concept or functional model
8. Relatively low-cost materials for creating prototypes
9. Implementing technology, such as layer-based manufacturing/rapid prototyping equipment, for quickly transforming ideas into reality, and
10. Forums to experiment with, test, or compete with generated designs

Building upon these characteristics, a number of key questions may be posed when creating designiettes for a course subject, across subjects, or for outreach activities. Table 4 lists the derived questions from our studies of the literature (Section III) and the foundations of designiettes (Section II). These questions are categorized according to the type of designiette, pedagogy and educational theories, scope of the designiette, testing process, and process for assessment and evaluation. Through the answering of these questions, clear directions may be formulating for creating a designiette or set of designiettes.

Table 4. Basic questions to direct the development of meaningful designiettes

Category	***Question***
Designiette Type	What type of designiette is being developed?
	What are the learning objectives of the designiette?
	Does the designiette provide adequate intrinsic motivation, such as being need-based and / or related to assistive technologies, health care, or the Grand Challenges?
	Is the designiette at the 1D, 2D, 3D, or 4D pedagogical level (4D Design Pedagogy)?
	Is the designiette intended to expose, explore, illustrate, or learn a subject matter concept or set of concept?
	Is the designiette intended to expose, explore, illustrate, or learn a design process or subset of a design process?
	Is the designiette intended to explore parametric design, modeling, simulation, and / or experimentation?
	Is the designiette intended for team competition; classroom, experiential wall, audience, or client presentation; homework or in-class experiences?
	Does the designiette address inclusion across gender, ethnicity, age, background, and experiences?
Scope	How much time will be invested by the students / participants?
	What monetary, personnel, space, and materials resources are available or chosen for the designiette?
	What type of facility will be used to conduct the designiette, such as cohort, reconfigurable classroom; lecture hall; laboratory; fabrication shop; or outside environment?
	What technologies are available to support the designiette?
	Will the designiette be performed in class or outside class by the students / participants?
	Will prototypes be created? What tools, instruments, and / or transducers are needed?
	Is the designiette intended to be focused or broad, virtual or physical, team or individual, or some combination?
Pedagogical and Educational Foundations	What innovation skills / mindset are intended to be developed in the students / participants?
	How is the designiette supported by and how does it develop local, national, and global contexts?
	What are the skills, personality types, learning styles, and demographic characteristics desired if a team designiette is intended?
	What active learning methodologies and techniques will be employed as part of the designiette?
	What phases of the Kolb cycle will be covered by the designiette? Does the designiette complement other phases of the Kolb cycle based on other course materials?
	What preparation is needed by the students / participants before being given the designiette?
	How does the designiette employ spiral learning and meta-cognition on the part of the students / participants?

Category	***Question***
	What thinking skills, according to Bloom's Revised Taxonomy, are intended to be explored and enriched by the designiette?
Testing	How will the designiette be tested before deploying to students / participants?
	What aspects of the designiette will be tested, and what are the associated testing procedures?
	How many times will the designiette be tested?
	How will the testing be evaluated: quantitatively, qualitatively, or mixed method?
	What professional development or training is needed to facilitate the designiette?
	What personnel roles are needed during execution and testing of the designiettes?
	What action items will be implemented based on testing results?
Assessment and Evaluation	What summative and /or formative assessments (data collection) and evaluations (data analysis) be conducted with respective to the learning outcomes and desired skill sets?
	Will the assessments and evaluations be quantitative, qualitative, or mixed methods?
	What rubrics need to be developed to support the assessment and evaluation?
	What specific techniques / methods will be employed?
	Will technology, such as clickers, be used as part of the assessment?
	How will the assessments and evaluations be used as part of the course, set of courses, program, or activity?
	How will the assessments and evaluations be used as part of student / participant learning?
	Will peer assessments and evaluations be used?

These characteristics and basic questions for creating a designiette may be formulated as a basic methodology, shown in Fig. 8. This methodology begins with clear definitions of the learning objectives, outcomes, and desired mindset and skill set from the designiette activity. Based on these learning objectives and expected outcomes, a set of the designiette characteristics are chosen (Table 3), in concert with answering the answering of the questions in Table 4. These characteristics and answers to the basic questions inform the design of the designiette, such that a design process ensues for developing the designiette as a curriculum element. Contemporary design processes may be employed to design and develop designiette concepts (Otto & Wood, 2001; Ulrich and Eppinger, 2004; Ullman, Dym, 2003). In conjunction, curriculum development tools, such as PHLIpS (Producing Hands-on Learning to InsPire Students Method) for Active Learning (Linsey, et al., 2008), may be applied to systematically develop the designiette concepts through prototyping and implementation.

After designing the designiette, a full procedure of the designiette is created, in conjunction with the associated assessment and evaluation instruments for student learning. These curriculum elements are then tested with in a pilot instruction environment and iteratively improved for deployment in the classroom. The role of testing cannot be minimized. As in the design of products, software, services, processes, and integrated systems, testing plays a key role in understanding and evolving a core designiette idea. Without appropriate testing, the potential of a designiette may not be realized. In fact, a designiette idea may fail, before it has an opportunity to succeed.

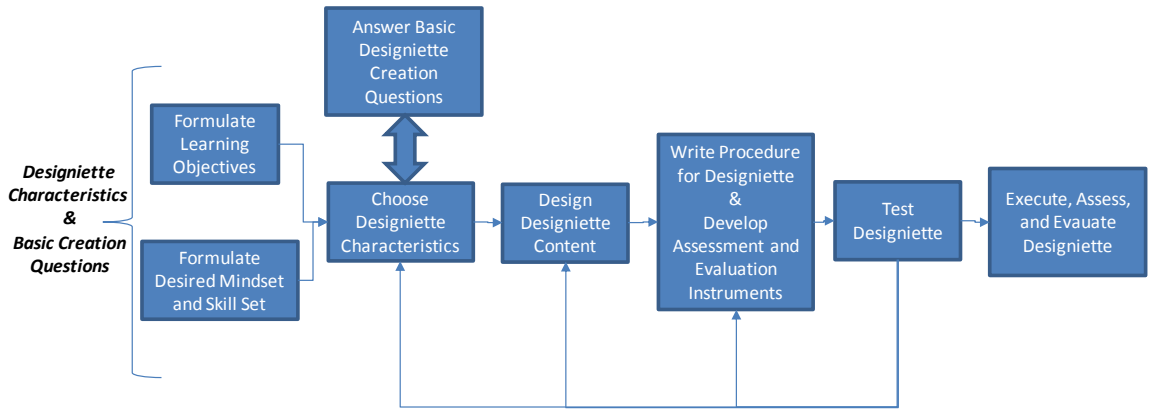


Figure 8. A basic methodology for creating designiettes

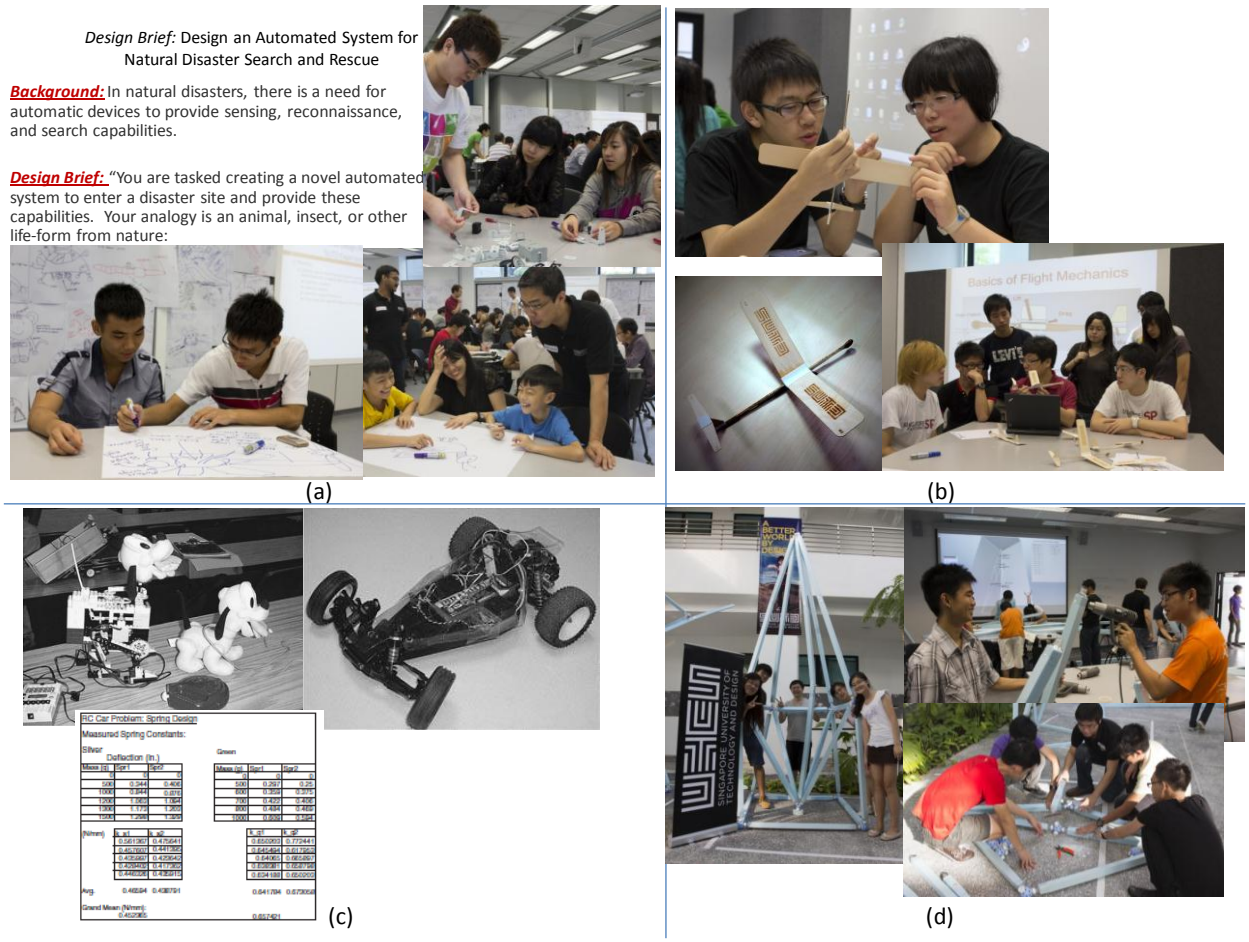


Figure 9. Exemplar designiettes

Design Brief: Design an Automated System for Natural Disaster Search and Rescue

Background: In natural disasters, there is a need for automatic devices to provide sensing, reconnaissance, and search capabilities.

Design Brief: "You are tasked creating a novel automated system to enter a disaster site and provide these capabilities. Your analogy is an animal, insect, or other life-form from nature:

- Process:
  - Choose one or more living creatures and sketch one or more ideas individually for a search and rescue MECHANIMAL (10 minutes)
    - Label the actuators
    - Label the sensors
    - Label the support structures
    - Think about the algorithm (brains) for controlling the MECHANIMAL
  - In your larger famous inventor teams, select the most preferred concept (5 minutes) for two criteria:
    - Most effective MECHANIMAL
    - Most robust MECHANIMAL
  - Choose a subsystem of the most preferred design and begin the construction of a subsystem, such as a leg, wing, tail, etc. (10 minutes)
  - Test / Experience a fully functional MECHANIMAL prototype (10 minutes)

Figure 10. Mechanical designiette, including DBL model, design brief, and motivating pictures.

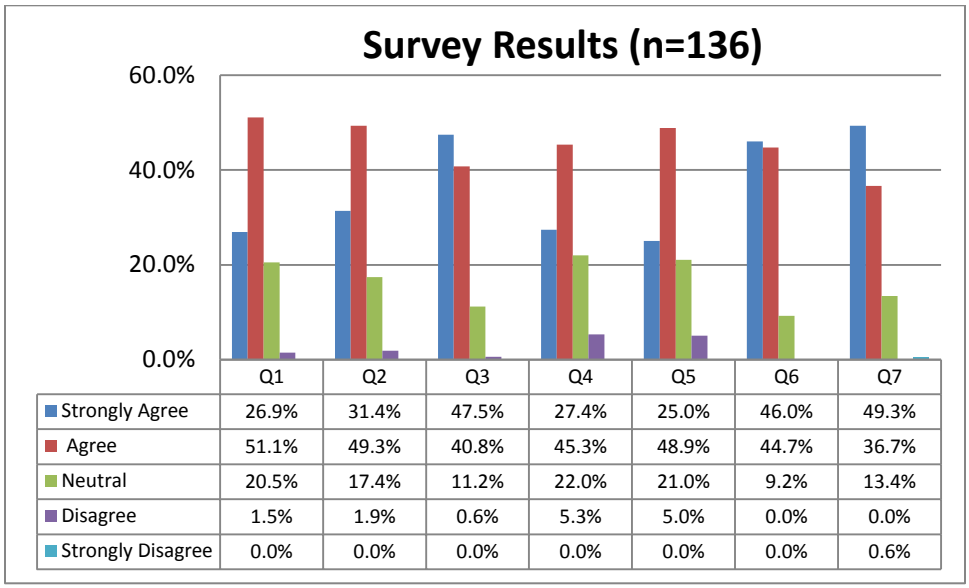
V. Exemplar Designiettes: Explorations in MechAnimals and Skyscrappers

Figure 9 shows four exemplar designiettes. The first segment of the figure shows a needs-based mechanimal designiette focusing on experiencing a design process (ideation, concept selection, prototyping, and testing) with robotics and automation type technologies. This designiette was created to introduce design to young students, typically at the secondary or freshman levels, and, in particular, it was used as part of Open House sessions to recruit students to engineering curricula in higher education. Figure 10 shows the Design-Based Learning model generally used in this designiette, as well as the design brief, timing and schedule, and introductory figures to the design problem, in this case disaster search and rescue systems. Approximately 400 students experienced this designiette in the Fall of 2011 and Spring of 2012 over 10 separate sessions of 40-50 students. Figure 11 shows pictures of students experiencing the designiette and includes a summary of assessment data. The data were gathered based on a survey assessment by the participants and demonstrate the positive experience encountered by the students and their generally positive self-assessment of learning.

The second segment of the Figure 9 shows a competition-based, exploratory designiette focusing on the analytical and experimental parametric design of a balsa and bass wood glider airplane. The third segment shows a reverse-engineering and parametric-design-based designiette in machine design. And the fourth segment shows a competition-based skyscraper design and construction designiette (architecture, structural design, and analytical design modeling. These designiettes were all motivated by or developed based, in whole or in part, on the characteristics, basic questions, and methodology discussed in Section IV. Let's consider the competition-based skyscraper design and construction designiette in more detail.

Figure 11. Mechanical designiette: exemplar session pictures and assessment data.

QUESTION		AVERAGE SESSIONS					STD DEV SESSIONS				
		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Q1	I have a sense of achievement from the rapid learning experience offered by the designiette	26.9%	51.1%	20.5%	1.5%	0.0%	0.07	0.14	0.08	0.02	0.00
Q2	The ways in which I was taught in the designiette provided me with opportunities to pursue my own learning	31.4%	49.3%	17.4%	1.9%	0.0%	0.06	0.10	0.03	0.02	0.00
Q3	The delivery fashion of the designiette developed my understanding of concepts better as compared to traditional classes	47.5%	40.8%	11.2%	0.6%	0.0%	0.03	0.05	0.06	0.01	0.00
Q4	I have received feedback that is constructive and helpful during the designiette	27.4%	45.3%	22.0%	5.3%	0.0%	0.07	0.07	0.10	0.02	0.00
Q5	The designiette experience enabled me to quickly connect and build relationship with fellow team members	25.0%	48.9%	21.0%	5.0%	0.0%	0.03	0.09	0.08	0.04	0.00
Q6	Overall I was satisfied with the quality of the designiette	46.0%	44.7%	9.2%	0.0%	0.0%	0.11	0.11	0.03	0.00	0.00
Q7	The designiette experience increased my interest in SUTD and its design centered technology curriculum	49.3%	36.7%	13.4%	0.0%	0.6%	0.08	0.10	0.04	0.00	0.01



Total sample size 136, where 54% where male, 32% female and 14% did not select gender


Automation-R




Automation-Robo


V.1 Summary: Architectural Explorations in Skyscrappers

The Skyscraper Designiette introduced architectural and engineering design concepts to prospective SUTD students through a collaborative learning and making experience of a large scale design prototype. Students were divided into teams and challenged to design, analyze and construct the tallest and the most spectacular skyscraper with respect to constraints such as budget, time, material, footprint and visual appearance. Over the course of three days we ran a total of five workshops with more than twenty-five teams of five to ten people each. Students were pleasantly surprised by the experience and outcome they managed to arrive at within such a short time frame.

V.2 Background

The designiette was developed based on the Design Activity conducted at the Franklin W. Olin College for the prospective engineering students in 2001 and 2002 (D. Frey, A. Horton, M. Somerville, ASEE/IEEE 2002). The format of a design activity provides a fantastic teamwork environment as well as a sense of excitement in building a large scale construction in a very short period of time. Our contribution in extending the design activity concept was by (a) providing an architectural context through a coupled massing and structure design of a skyscraper (b) introducing contemporary design methodology by developing and using a simplified computer aided design and finite element analysis application and (c) optimizing the design to construction process by employing building information modeling principles along with a prefabricated erector-set type tectonic system.

V.3 Designiette Structure

The designiette was organized into three segments (a) a ten minute interactive discussion and training (b) a twenty minute design and review and (c) a thirty minute fabrication and assembly segments. The time ratio between segments was calibrated after extensive testing iterations with previously enrolled students.

A short introductory presentation on tall buildings design provided a brief historical background on the evolution of tall buildings and their contextual relevance today; an inspirational and aspirational basis of the design exercise with the goal of adding some perspective as well as a lightweight formalization thereof. The training component introduced foundations of structural stability such as the triangulation of spatial lattices and as well as an interactive training session on CAD and FEA (Fig. 12). The design brief explained the aforementioned design goals and laid out the constraints of: five thousand virtual dollars which could be spent on materials and building parcel footprint area costs. Students were provided with workstations, sketch boards and stationary as well as a computer with a wall projection per team.

During design and review students discussed and debated their design aims, communicated visually through sketching design concepts, modeled and analyzed their skyscraper design. Each team was supported by a tutor that offered design feedback and assisted with technical QnA. Teams were encouraged to structure their goals towards aesthetic appeal, shear building height, material and construction efficiency or combinations thereof. The goal of this segment was to challenge the participants into tackling an ill-defined problem bound by multiple and conflicting constraints while provisioning the implications of design action from the concept and schematic phases of design to its fabrication and construction.

Figure 12. Design segment

In the final segment of the fabrication and construction students were challenged with the physical production of their design. Their tasks were multiple and diverse: (a) measure and cut linear foam members (b) weld multiple parts together to form long beam elements and mount joints at their ends and (c) assemble a three-dimensional lattice using ball-joint connectors. Naturally these tasks mandate for role specialization and tight team work cooperation and coordination. The tutors assisted with demonstrating the necessary procedures and taking care of safety. Each team was provided with twenty five linear elements, thirty PET bottle sockets and ten ball joints as well as equipment such as measuring tapes, hot wire foam cutters, cable ties for mounting bottle caps onto ball-joints and heat guns for welding bottles onto the beam members (Fig. 13).

V.4 Architectural

The scope of a fast-paced design exercise cannot encompass the numerous architectural considerations involved in the conceptual design of a tall building. We thus limited the aspect of the designette to addressing the issue of the overall building shape, commonly known as the massing exercise, which is conveniently compatible in terms of timing and scale with the phase of mega-structure engineering design. Our aim was to guide students into the design of a building form evocative of spatial qualities in terms of scale, proportion and enclosure and avoid spire or antenna design solutions. The description or brief of the workshop also called for not merely for an objectively evaluated tall structure but also an inspiring one. The best design by standing height and tutors' vote was awarded with a symbolic design excellence trophy.

V.5 Digital Design

The software used in the designiette was developed as an interactive educational tool where geometric, structural and resource simulations are integrated into a limited but comprehensive and fluid digital design process (Fig. 13). The computer application is derived from past work of S. Kaijima and P. Michalatos (Critical Digital, 2008). Its user interface was designed such as students could rapidly acquire three dimensional drawing skills; an experience not more complicated than a contemporary video game. Students designed their skyscraper as a network of elements and nodes, and performed real-time FEM analyses to observe the structural behaviour of their designs, towards static dead-load scenarios as well as dynamic wind-load circumstances. Physical tests were conducted in order to calibrate the physical system's behaviour with the simulation tool. Basic design metrics such as buildings height, plot area usage, resource consumption, virtual cost and constructions scheduling information where updated in real-time so as to provide direct design feedback. As a result the latency between concept design actions and end-product repercussions was so drastically reduced that allowed for a rather more playful, intuitive and informed exploration of design ideas.

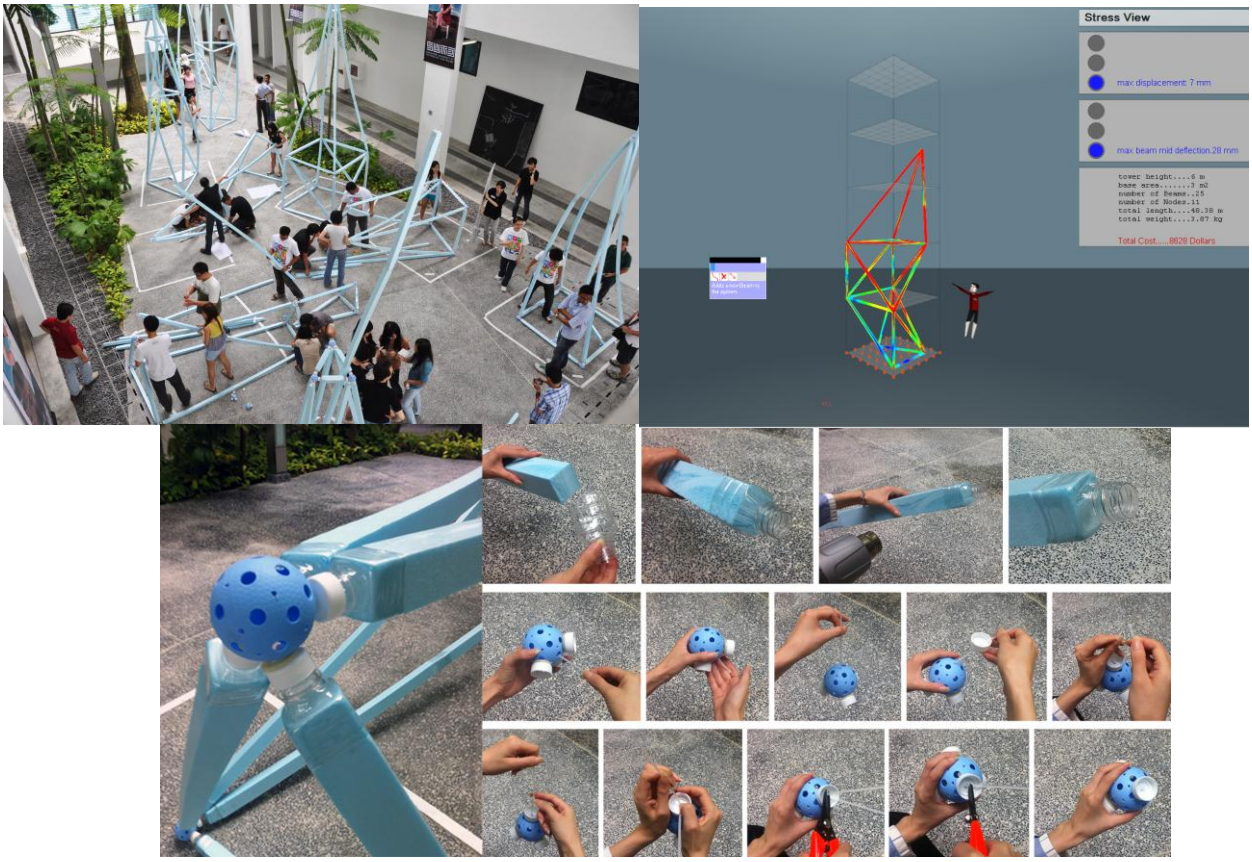


Figure 13. Construction phase, design modeling, ball-socket joints and tectonic system

V.6 Tectonic

A ball-and-stick design tectonic system was developed in conjunction with the simulation tool (Fig. 13). It was comprised of partially prefabricated components, namely standard 2"x2"x4' XPS foam linear elements, pre-drilled at various angles floor-ball nodes and pre-cut PET plastic bottles such that the cap was secured on the ball via a cable tie knot and the nozzle part of the plastic bottle was heat shrunk onto the end of the foam element. Longer than 4'elements could be produced by heat welding two or more elements using the middle portion of said PET bottles, while shorter elements could be cut via supplied how wire cutters. Cable tie connections between the ball-joints and bottle caps where used as design to construction tolerance buffer in case of linear measurement/abrasive errors and angular variances. In

effect the students had to read off the building scheduling information, produce the linear members, weld end-joints and assemble their structure following the connectivity as displayed in their simulation tool.

V.7 Introspection

In the Skyscraper Designiette, students with no prior architecture or structural engineering background were called to design and construct large scale skyscraper mockups, ten to twenty feet high, in a short period of time, approximately an hour. On-site construction generally exceeded the time requirement due to complex geometries which signals the need for further assistance and time-compression via perhaps member size rationalization and automated generation of IKEA™ style assembly instructions manuals. The cost and preparation time of prefabricated parts could also be improved.

Overall, students expressed their excitement and a sense of achievement for the rapid learning experience, using sophisticated design tools and constructing hand-on large scale objects as sketched on screen. Each team came up with a unique design solution, some of which were quite surprising (Fig. 14).

Figure 14. Teamwork and final designs

As computer aided analysis, design and manufacturing become more pervasive in design education and practice we find that workshops such that skyscraper designiette may help students understand the dynamics between work within digital media and their physical repercussions in an interactive, hands-on and exciting mode. The sheer scale of building a larger than a traditional table top design prototypes was also a key contributing factor towards team building the element of surprise and achievement.

VI. Discussion and Conclusions

Designiettes represent a unique opportunity to integrate design throughout engineering curricula. This opportunity overcomes the compartmentalization of design. Instead, design becomes a spectrum and continuum of experiences in the innovation skill set and mindset of students.

This paper recognizes the area of designiettes and initiates a discussion of the scholarly study of designiettes. A sample literature review leads to designiette characteristics, basic creation questions, and a skeletal methodology. Through these elements, effective designiettes are possible and tractable, building upon the foundations of active learning, the Kolb cycle, Bloom's taxonomy, personality dimensions, and visions of the I-Engineer.

These are but the first stepping stones in the investigation of designiettes. The possibilities are endless. Basic principles, guidelines, and assessment techniques are around the corner as we contemplate and develop our understanding of these possibilities.

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