Beyond LEED®: Constructing a Bridge to Biomimicry for Canadian Interior Design Educators

by

Karen Cash

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ABSTRACT

Interior designers require advanced sustainable strategies beyond the Leadership in Energy and Environmental Design (LEED) rating system to expand their ecological accountability. Biomimicry is a biology inspired design (BID) methodology that is integrating into U.S. interior design (ID) curricula. This thesis research aims to identify the extent to which biomimicry is taught in Canadian post-secondary ID programs. Through a mixed-methodology research design, this study explored the strategies and lessons learned from North America interior design educators teaching biomimicry.

Integrating a science-based problem-solving methodology into design education requires a transition strategy that includes both high-tech and low-tech teaching tools. This study discusses avenues to heighten biomimicry awareness, for Canadian educators, and addresses the challenges that weaving a complex multidisciplinary topic into interior design pedagogy will bring. Future research regarding biomimicry applications from interior design learner and practitioner perspectives would complement this study, and inform bio-design curricula development.

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DEDICATION

This thesis is dedicated to my husband, Steve, who supported me with unwavering support, and was a pillar of patience on a not-so-smooth journey.

Also remembered is my father (1923-2015) who did not live to see my thesis published, but who taught me that learning is a life long journey.

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1.0 Introduction

Interior design (ID) education encompasses a broad range of topics and skillsets that students will require to navigate real-world project challenges as practitioners. ID students must not only acquire knowledge specific to their discipline but also have a basic understanding of the other design-related disciplines that they will interact with on project work such as architecture and electrical, mechanical and acoustical engineering. Educators require a wide range of teaching strategies to deliver this knowledge and these skillsets to their interior design students who are creative thinkers with various learner styles. "Post-secondary design curricula typically balance studio-based instruction, which teaches design as an action or skill, and technical subjects" along with other methodologies, according to Orthel (2015, p.5). ID education is delivered in different ways that include lectures, labs, and field studies. Studio-based instruction is the teaching strategy where students practice the creative, critical-thinking, and collaboration skillsets that they will use most as practitioners (Lackney, 1999).

ID schools are challenged to not simply meet but exceed the expectations of the practitioners who will employ their graduates. Teaching advanced sustainable design (SD) strategies that affect the health and wellbeing of building occupants and the environment has become essential. Educators must look beyond traditional SD benchmarks and seek out new knowledge that will provide ecologically positive design strategies for their students and the planet. Biomimicry is one of those strategies that is becoming a biology inspired design (BID) methodology taught in North American post-secondary ID education. My thesis study explores teaching methods, models, tools and

learning outcomes from educators teaching biomimicry that could advance its deeper integration into Canadian interior design curricula.

"Bi-o-mim-ic-ry (from the Greek *bios* - life and *mimesis* - imitation)" (Benyus, 1997) is more than just a hybridism or combination of terms. Biomimicry is a SD methodology that inspires designers and manufacturers to look to nature to solve human problems. "Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies" (Benyus, 2011) and models the way nature 'acts' versus the way nature 'looks' (Benyus, 1997). BID pertains to the broad spectrum of problem-solving activities in various disciplines when biology informs the design process (CBID, 2015). Biomimicry is one of these strategies. A biomimicry tool created by Biomimicry 3.8, referred to as Life's Principles (Figure 9), provides design professionals with a biologically inspired design (BID) framework that contribute to advancing sustainability in the built environment.

The relationship between biology and the built environment is not a new concept. Evidence of what nature can teach us can be observed as far back as Leonardo da Vinci's sketches for flight (Niewiarowski & Paige, 2011). Henry David Thoreau's (1817-1862) literary accounts at Walden Pond[1] in 1845 heightened public awareness of the human-nature connection in modern society (Witherell & Dubrulle, 1995). There have been many advocates of integrating biology into design and architecture since the

[1] Walden Pond was a sixty-two-acre pond on a friend of Thoreau's property in Massachusetts where Thoreau built a house to reside alone in during his 26-month experiment in simple living (Witherell, 1995)

1800s, however it was not until industrialization started to seriously foul and deplete our natural resources that the importance of taking measures to protect the environment the was publicly recognized.

Benyus (a biologist), McDonough (an architect), and Anderson (a manufacturer) were the early biomimicry pioneers and innovation leaders. They have inspired the current protagonists in the 'theory-to-delivery' biomimicry journey, and provide models for industry and education to follow. The biomimicry methodology fosters multidisciplinary teams and values designers as an integral part of the design development process. Founded in 2005, the Biomimicry Institute founders, Janine Benyus and Bryony Schwan, recognized that teams comprising of multiple expertise provide the optimum results for a projects' outcome and desirability in globally diverse, socioeconomic climates. Multidisciplinary teams that include biologists, economists, and designers were valuable allies. According to Benyus (1997) "…designing may be the most powerful fulcrum which we can move the economy and the culture toward a more sustainable place" (pp.281-282). Designers connect theory to practice, and translate ideas into consumer products functionally and aesthetically (Benyus, 1997). Benyus (2011) believes that we live in a sustainable world, and that biomimicry provides a strategy for designers to learn from and contribute to nature with purpose, as oppose to deplete it.

The awareness and value of alternative ecology-based utilization strategies in design and manufacturing has increased exponentially since Benyus (1997) coined the term 'biomimicry' in her seminal book *Biomimicry: Innovation Inspired by Nature*. The Cradle to Cradle (C2C) design methodology is an example of a closed-loop design

strategy that integrates BID principles. This an earth-friendly model that design practitioners are utilizing to reduce the ecological impact from the built environment (McDonough & Braungart, 2009). Closed-loop design methodologies (Figure 1) can lead to minimizing the amount of construction waste contributing to landfills and replenishment of natural resources. The flow pattern at the top of Figure 1 illustrates the linear, or open-loop design, that human-made products typically travel throughout their life cycle (from raw materials to end-of-life), as well as how this traditional linear process can be disrupted and rerouted into a closed-loop design, using ecology-based utilization strategies.

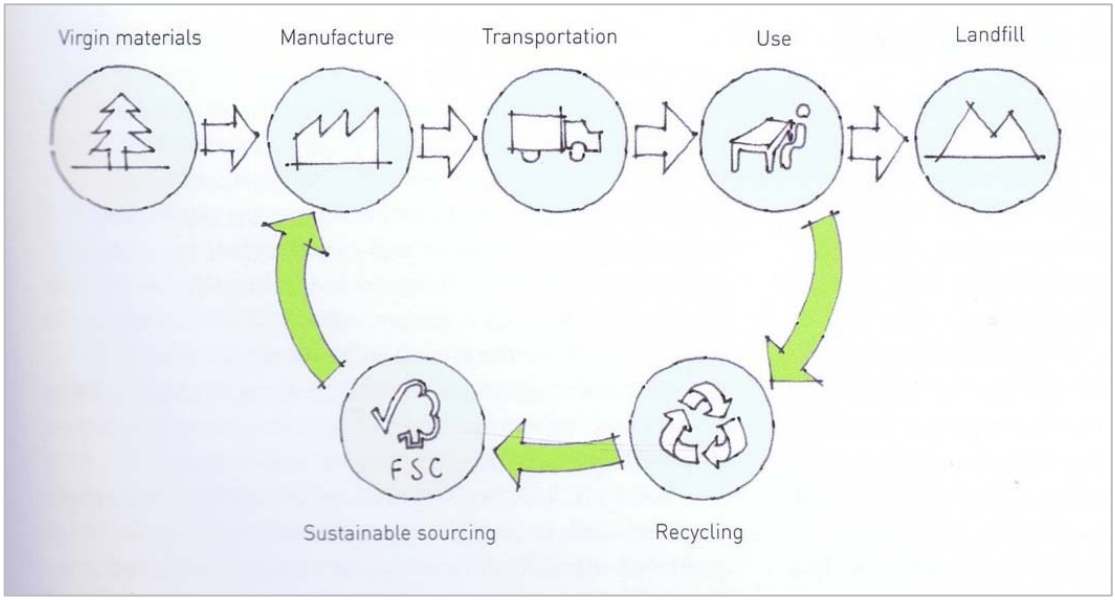

Figure 1: A sustainable life cycle forms a closed loop, with all by products being reused. An unsustainable life cycle is a linear model, with waste as its outcome. (Image by Nick Hacking, *Sustainability in Interior Design*, Moxon, 2012. Used with permission.)

Biomimicry is a BID and SD methodology that provides the opportunity for ongoing ecological discourse across disciplines with principles and tools to inform design development (Benyus, 2011). The collaborative approach to biomimicry teaming

aligns with the integrated design process (IDP), a current Leadership in Energy and Environmental Design (LEED) credit to advance the linkages between the disciplines in the design and construction of built environments. "The role of the designer in the product development team is expanded when biomimicry informs the process" (Verbeek, 2011, p.3). Advanced SD strategies, like biomimicry, contribute to design professional proficiencies, increasing design demand and consulting opportunities that, in turn, contribute to the professions' sustainability. Sorrento (2012) observes that interior design in the U.S. has often been underemphasized in environmental agendas in comparison to other design disciplines, and states that "interior designers must be in the forefront of changing how others in the building and sustainability industries see the world and, in turn, our work" (2012, p.x).

The Biomimicry Institutes' AskNature online database supports designers with rich resource of BID inspired products and evidence-based innovation, vital to advance the understanding and application of biomimicry. Karpan (2005) writes,

> In interior design, a growing number of stakeholders consider research to be a critical factor that will lead to an expanded and specialized body of knowledge, professional recognition, disciplinary status, and legitimization and sustainability of the profession. Attaining these goals would mark the evolution of interior design from its current position as an art-based profession to the more highly valued position of a research- or evidence-based profession. (p.2)

Biomimicry research empowers design teams with an expanded body of knowledge (BOK) that elevates their ability to contribute to ecological preservation. AskNature is a

contemporary model of an “online library of research articles indexed by function” (Helms et al., 2009, p.607). AskNature, an ever-expanding product resource of BID innovation, illustrates in real-world scenarios, how human problems can be solved by looking to nature for answers.

1.1 Problem Statement

It is the role of institutions of higher education to graduate students well versed in leading-edge concepts relevant to their future career responsibilities. ID is the discipline that is largely responsible for the development of the design vision, space programming, material selection, and construction specifications in the creation of interior environments. In collaboration with related disciplines, to meet mechanical, electrical, and life safety requirements, interior designers often manage the full scope of the project from site selection, through to and including the post occupancy evaluation (POE). However, interior designers are rarely responsible for the project deconstruction process, with the exception of building renovations. With carbon emissions polluting our air and building construction waste growing our landfill sites, interior designers must become more responsible for their project life cycles. Interior designers can make ecologically positive decisions at the conceptual design stages of their project development that could allow for disassembly, reuse, and recycling, and play a bigger role in the reduction of construction waste. Canadian interior designers require new knowledge and new problem-solving strategies to guide their SD decisions, or be succeeded by their U.S. peers and other ecology-minded project team members.

“Biomimicry is one of the tools that can expand the capability of future designers in creating more sustainable designs and systems. An understanding of biomimicry

principles can teach future designers to examine nature's models, systems, process, and elements for sustainable solutions used by nature's best adaptors to solve existing human needs with minimum impact" (Frasier-Scott, 2012, p.18). LEED and other SD strategies are required components of the Council for Interior Design Accreditation (CIDA) criteria for ID curricula, and designers' BOK. Interior designers, according to Coleman (2015), need to be cognizant of the importance to continually expand their BOK, and build the skill sets required to take on significant roles in multidisciplinary projects. Educators teaching biomimicry do not debate its value as an advanced SD strategy deliver, however the best models for delivering a BID topic to the design student in a non-biology-based discipline is unresolved (Remington-Doucette, Hiller Connell, Armstrong & Musgrove, 2013).

Additionally, the time required to obtain this new knowledge, and develop the curricula to integrate this complex multidisciplinary topic, is a challenge widely discussed among academics. How will Canadian interior designers meet the ever-increasing responsibility to develop their ecological consciousness and the preservation of our natural resources if not through education? Will they need to seek other learning avenues to develop their ecological mindfulness?

A 2012 study, presented by Sarah Angne at the Second Annual Biomimicry in Higher Education Webinar, revealed that 56% of the United States (U.S.) ID educators employ biomimicry principles in post-secondary courses (Angne, 2012). The study, that surveyed 500 members from the Interior Design Educators Council (IDEC), resulted in 50 respondents, 90% of whom responded that they were familiar with biomimicry. Angne's survey investigated to what extent and in what context biomimicry was taught

in the U.S., and with what methodologies. The findings of the survey revealed that 56% of the questionnaire participants weave biomimicry into their undergraduate and graduate programs, and that 50% teach it themselves. Based on her research, Angne (2012), an ID educator, developed a pilot course that introduced biomimicry to her ID students the Art Institute of California-Inland Empire. Angne's study summarized her course delivery design, and revealed first-hand accounts of educator and student experiences in an ID context. Delivering biomimicry education to ID students was unique in my research at that point, as the students in most studies involved science, technology, engineering and mathematic (STEM) disciplines. Based on the theory-to-practice methodology and course assessment that Angne presented in her study, my thesis research set out to build on her findings, investigate other educator experiences, and gain a broader understanding of the issues and challenges surrounding biomimicry in ID education. My preliminary research suggested that there was a growing number of biomimicry courses in the U.S., but only one course available to ID students in Canada. What did these early findings indicate about advanced SD education in Canada, and what value could biomimicry bring to the ID profession?

1.2 The Purpose and Goals of this Study

With biomimicry knowledge becoming increasing accessible online, this thesis study endeavoured to learn the extent to which North American ID education is responding to and integrating this swell of BID research and innovation. Further to this, the purpose of this study is to expand my investigation into the status of biomimicry in ID programs in Canada today, reveal potential advancements that U.S. educators have made in that respect, and understand the lessons learned by them. How do Canadian

ID programs compare to those integrating biomimicry in the U.S.? To achieve this, I first identified BID integrated courses focused on biomimicry, and then collected data about them. What tools are interior design educators using to teach biomimicry? What are the challenges and outcomes? What, if any, are the additional tools or strategies required to develop teaching methodologies further? By seeking out examples of how North American educators introduce and integrate biomimicry into their ID courses, this study targets to determine the repeatable methodologies that will guide Canadian ID educators in the BID quest.

Ecological literacy is paramount according to Orr (1992), and this study endeavours to understand if educators are equipped with the methodology, tools, and/or resources to deliver biomimicry literacy to Canadian ID students, the industry's future practitioners. By equipping ID students with biomimicry knowledge and a heightened ecological conscientiousness, they will enter the workforce with skill sets to maximize their contributions on multidisciplinary project teams. Design professionals with the heightened awareness of the "input" (consumption) and "output" (waste) repercussions of their design decisions will be valuable IDP team members (Stieg, 2006, p.viii). Biomimicry strategies will empower ID students with advanced SD knowledge and application tools to become leading ecology-minded practitioners.

1.3 Research Questions

In order to develop a methodology for educators to integrate biomimicry into ID curricula, my research focused on understanding BID teaching methodologies and student learning outcomes. Four key questions guided my research:

1.3.1 Inquiry 1: how nature serves as model, measure, and mentor

- What lessons can nature teach interior designers about ecological sustainability in the built environment?
- What are the principles, practices, and primary concepts that are important for interior designers utilizing biomimicry?
- Who are the mentors and what can we learn from them?

1.3.2 Inquiry 2: ID curricula development

- How do educators integrate new topics into curricula?
- What are the motivations for teaching biology-based concepts?
- How does biomimicry relate to the accreditation of ID programs, and contribute to the BOK?

1.3.3 Inquiry 3: exploring biomimicry in ID education

- To what extent is biomimicry taught in Canadian ID programs?
- What methodologies are employed for teaching biomimicry?
- What challenges are ID educators and students experiencing?

1.3.4 Inquiry 4: considerations for advancing biomimicry education

- What are the utilization strategies and synergies of biomimicry?
- What tools are available and required to assist educators looking to introduce or develop biomimicry education, and what is the framework that will best weave this topic into design curricula?
- What do educators who teach biomimicry advise educators who want to?

The goal of this study was to learn from the experienced educators teaching biomimicry, and develop a conceptual framework to guide Canadian ID educators in

their biomimicry pursuits. Based on the value of evidence-based design (Karpan, 2005), this thesis considers biomimicry an effective means for interior designers to advance their BOK, and reinforce CIDA'S future vision (Coleman, 2015) for the ID profession.

1.4 Assumptions and Limitations

As a design practitioner for more than three decades, and a LEED Accredited Professional since 2007, I have based this thesis on certain assumptions. These assumptions are that: (a) Canadian post-secondary ID educators are open to introducing biology-based topics into their curricula, (b) ID students will engage positively in BID methodologies, (c) institutions, teachers, and students will support multidisciplinary learning, and (d) practitioners will seek to employ ID graduates with BID skillsets beyond LEED. With LEED being an accepted norm in building construction today, my assumption is that students will embrace BID education, welcome the opportunity to increase their competitive edge in the marketplace based on new knowledge and skillsets, and develop an ecological worldview.

One limitation of the study is that there is a lack of research from Canadian sources on biomimicry and BID topics. Additionally, without access to detailed course syllabi, the precedent study and research involving ID programs is based on information published primarily on institution websites (which may not be highly detailed or up-to-date). The selection of the survey candidates was equally challenging due to the significantly fewer ID programs in Canada as compared to the U.S. Selecting an equal number of similar representative samples from both countries was not possible, and therefore selection criteria was modified for Canadian participants. Although the Canadian ID programs are identified on the IDEC website, per Angne's survey selection

process, only 6 Canadian ID programs have met CIDA guidelines as opposed to 117 in the U.S. The survey outcomes are a direct result of the number of questionnaire responses received and the educators that volunteered for semi-structured interviews. Consequently, the data analysis is challenging to compare due the differing response rates between the two countries. The results of the questionnaire and interview surveys are located in Chapter 4 and a copy of the questionnaire analysis is in Appendix D.

1.5 Chapter Outline

Having introduced the thesis topic and research goals in this chapter, Chapter 2.0 Research Methods, outlines the research design. That chapter outlines the data collection methodologies, including the: literature review, questionnaire, semi-structured interviews, precedent studies, and strategies for the data analysis.

Chapter 3.0 Literature Review Findings identifies the evolving methodologies in BID and biomimicry, and the application strategies that could provide the most transferrable framework for ID curricula. As well, the chapter discusses biomimicry strategies applicable to ID education curricula development and accreditation criteria.

Chapter 4.0 Survey Findings and Discussions outlines the outcomes of the survey targeted at North American ID educators to understand the extent and context to which biomimicry exists as an advanced sustainable design strategy in their programs. This chapter also includes a precedent study of seven design-related university courses that currently integrate biomimicry and/or BID into their curricula. Based on the findings from the research and data analysis, this chapter comments on the current state of biomimicry integration it relates to ID education in North America today. It also reveals

the roadblocks and gaps that educators incur in the utilization of BID concepts, and presents the lessons learned in the delivery BID and biomimicry education.

Chapter 5.0 Building a Bridge to Biomimicry Education for Canadian ID Educators proposes a conceptual framework to advance the integration of biomimicry in Canadian ID programs. This chapter outlines a transformative process through a conceptual framework for Canadian educators to integrate biomimicry into ID curricula.

Lastly, Chapter 6.0 Final Summary, Recommendations and Conclusions summarizes the research findings and observations. Further research directions are proposed in this concluding chapter to provide a view to what the future vision of biomimicry could be for ID educators and their students.

A Glossary of Terms can be located in Appendix A.

2.0 Research Methods

2.1 Research Design

The purpose of this research design was to collect a diversity of data that would clarify the extent to which biomimicry has been integrated into North American ID education. Figure 2 illustrates the mixed-method research strategy for this thesis study comprising of: a literature review, a questionnaire survey, semi-structured interviews, and a precedent study of biology inspired design (BID) and biomimicry courses, concluding in the development of a conceptual framework.

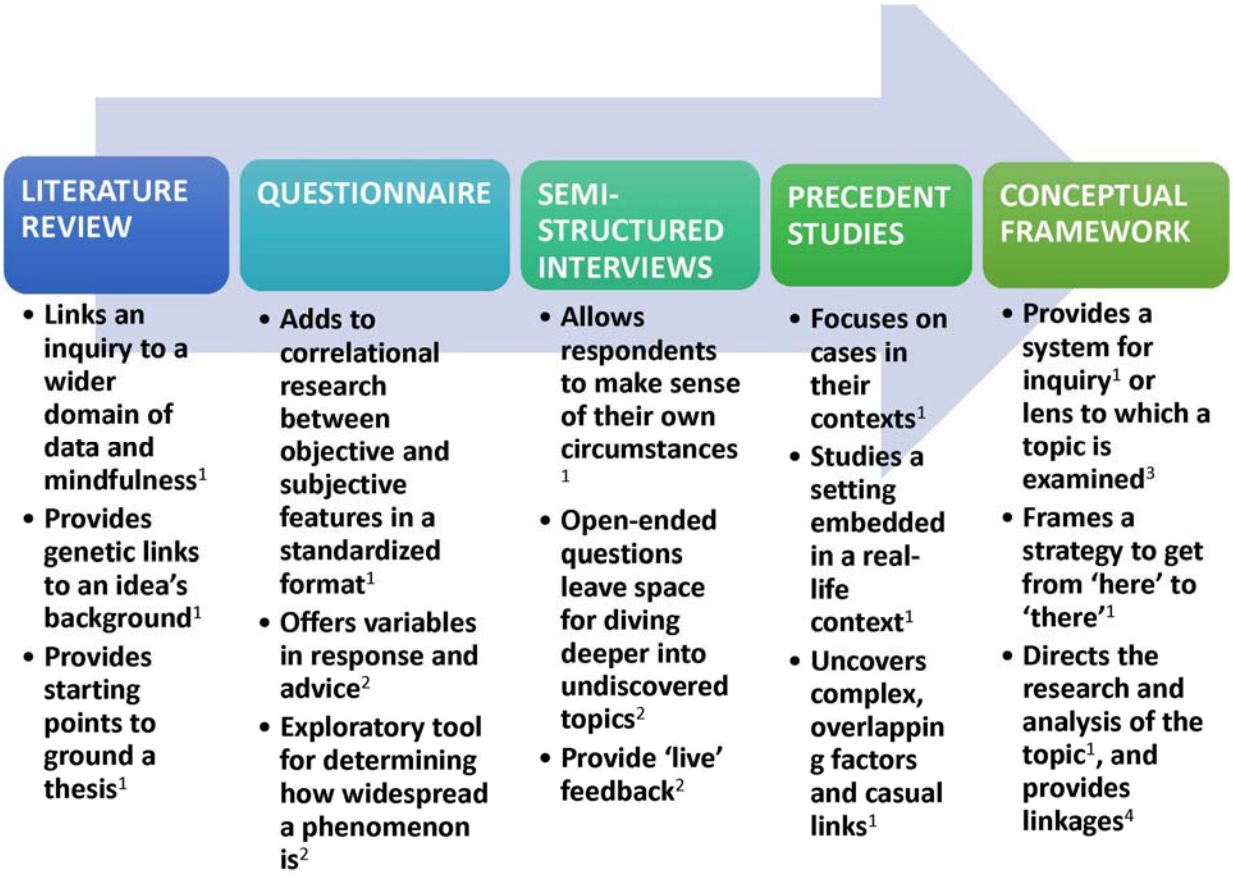

Figure 2: Mixed-method Research Strategy
Concepts adapted by author from: 1. Groat & Wang (2002); 2. Rugg & Petre (2007); 3. Trent University (n.d.); 4. Karpan (2005)

“Increasingly, researchers in many fields, including architectural, are advocating a more integrative approach to research whereby multiple methods from diverse traditions are incorporated in one study” according to Groat and Wang (2002, p.361). One of the benefits of using a combination of data collection methods, suggests Groat and Wang (2002), is that the researcher has the ability to balance the strengths and weaknesses of each tactic. I utilized a mixed-method research strategy on that basis that it would provide both a quantitative and qualitative understanding of the extent and methods biomimicry is taught to ID students in North America, and particularly in Canada.

My thesis research commenced with a literature review, and similar to Angne’s 2012 study introduced in Chapter 1, involved a questionnaire survey to ID educators. Angne’s paper, Biomimicry: An Interior Design Teaching Tool, was unique to other studies as it specifically surveyed ID educators. Angne’s 2010 survey findings provided new data to understand how many and to what extent U.S. educators were integrating biomimicry into their ID programs. That research provided a domain-specific baseline for my questionnaire survey analysis. In addition to a literature review and questionnaire survey, my mixed-method thesis research design included semi-structured interviews, and a precedent study, for a broader understanding of the issues involved when integrating biomimicry into Canadian ID curricula.

2.2 Literature Review

A review of literature was selected as the initial exploration tool to attain a broad understanding of the origins and development of biomimicry. A literature review forms a foundation for the key sources, theories, debates and issues on a topic (Groat & Wang, 2002). Not only does this methodology inform the researcher, but it also provides a

platform on which to guide and validate the thesis development, as well as identify gaps where future research is required (Rugg & Petre, 2007). The focus of this literature review, described in Chapter 3, sought to identify common concepts, new developments, and key players in biomimicry innovation and education. It was equally important that the review exposed gaps, challenges, and potential controversies regarding biomimicry teaching strategies and tools in design-related disciplines. In sourcing the BID research, the goal was to trace the origins and development of the topic to gain a broad perspective on its development and integration into ID education. From that basis, my search narrowed to locate curricula, tools, and techniques for teaching biomimicry in ID programs.

The literature search was entirely internet-based including to source online data and digital media, access webinars and podcasts, video-sharing websites (like TEDtalks and YouTube), and to order printed materials. The sources referenced in this study include a combination of books and published journal articles from various online repositories of scholarly research, for example university libraries, Science Direct, Wiley, and Springer websites. Online publications, regularly reviewed for BID and biomimicry content, include the Journal of Interior Design, Zygote Quarterly, SABMag, as well as blogs from HOK, Terrapin Bright Green, and the Environmental Design Research Association (EDRA). Numerous ecology-focused organizations were monitored for current research, including the Biomimicry Institute, Disruptive Foundation, International Living Future Institute, Sustainable Brands Innovation, Cradle to Cradle Products Innovation Institute, U.S. and Canadian Green Building Councils, Environmental Design Research Association, Interior Design Educators Council, Ellen

MacArthur Foundation, and Buckminster Fuller Foundation. As well, studies were sourced from conference proceedings accessed using Google Scholar web-searches. Among the various words and terms that applied to my online searches for data, those that provided the most relevant results were biomimicry, biologically inspired design (BID), biomimetics, and ecological design. The literature review provided a baseline of BID and biomimicry development, and a context for the survey design.

2.3 Surveys

The next research phase comprised of two surveys of anonymous post-secondary ID educators across North America, and involved a questionnaire and semi-structured interviews. A prime purpose to utilizing survey methodology is to obtain current data in a "realistic setting" according to Rugg and Petre (2007, p.71). "The great advantage of survey questionnaires is that they enable the researcher to cover an extensive amount of information - from demographic characteristics to behavioural habits, to opinions or attitudes on a variety of topics - across a large number of people in a limited amount of time" states Groat and Wang (2002, p.219). These survey tactics facilitated an inquiry to educators from two countries, and provided a combination of statistical data and lessons learned.

The questionnaire (see Appendix D) design inquiry surveyed educator experiences to ascertain to what extent and in what context biomimicry was being taught to ID students. Those findings provided a database for comparing Canadian educator responses to their U.S. peers. The educator pool from which questionnaire participants were selected was far less in Canada, based on the numbers of interior design programs offered, than it was in the U.S. For this reason, the questionnaire

results may not represent the full extent of how biomimicry is comingling with ID education in Canada, however attempts to establish “an agreed set of conventions” from which to further this study (Rugg & Petre, 2007, p.61). In order to elicit more detailed responses, beyond ‘yes’ or ‘no’ answers, the questionnaire was constructed using multiple-choice questions. The open-ended questions provided the participants more opportunities for detailed responses, and to add additional comments wherever applicable. Similar to Angne’s 2010 research, my questionnaire sought to understand what the baseline of biomimicry education was in the ID programs surveyed, the context it was taught within (or if not, why not), what and how the related skill sets integrated into the curricula, and what was learned. The data collected from the U.S. was analysed to determine if and how the integration of BID, in particular biomimicry, had progressed in the four years between my survey and Angne’s (2012).

The questionnaire also provided a pool of potential interview participants from which discussions about biomimicry education could be further explored. A semi-structured interview format was designed for those questionnaire respondent interviews. In combining structured and unstructured interview components, there remained a flexibility in case a question “freezes the interviewee” (Booth, Colomb & Williams, 2008, p.82) and interrupts the flow of the discussion which is usually time sensitive. A semi-structured interview “leaves space for following up interesting topics when they arise” observes Rugg and Petre (2007, pg.138). The interviews started with a structured discussion that pertained directly to the questionnaire survey, addressing clarifications or ‘skipped’ questions, while the unstructured portion allowed time for the educators to

provide first-hand accounts of their own experiences anonymously, and offer additional advice at their own discretion (Groat & Wang, 2002).

The semi-structured interviews (Phase 3) were undertaken with volunteers who responded from the questionnaire survey. The interviewee identities are not included in the summary of discussions. However, some background on the educators has been included wherever possible. Each telephone interview was 15-30 minutes depending on the availability of the interviewee. As noted in Figure 2, the semi-structured interviews provided time to return to the questionnaire to clarify answers if necessary and put their responses in context (Groat & Wang, 2002). The unstructured aspect of the interviews intended to provide live feedback, and leave space for deeper discussions to occur on issues involving biomimicry based on their educator experiences (Rugg & Petre, 2007). The educators that volunteered were from both countries, and all but one taught BID. That educator provided insights into the reasons why a program might be unable to introduce new topics into their current curricula. The findings of the surveys are presented in Chapter 4, Survey Findings and Discussions.

2.3.1 Questionnaire Participant Selection

The initial selection criteria for the questionnaire participants focused on educators from degree-granting post-secondary institutions, and listed on the IDEC (2013) website as teaching a program with an interior design emphasis. ID programs that specified SD, environmental, or ecology-minded content in their course descriptions were selected over those that did not. As the number of participants in Canada and the

U.S. were significantly different, the selection criteria was modified for the Canadian participants so to survey an equal number of educators respectively.

The U.S. participants that met the above criteria were shortlisted from the list of respondents from Angne's 2010 survey that specifically reported to have SD and BID content in their respective curricula. Adjustments were made to the U.S. participant list because of one-on-one educator discussions at the 2014 IDEC conference. Four U.S. educators, who met the selection guidelines, offered to participate in the survey and were included. The final participant list was based on those the institutions who taught programs that most closely met the BID selection criteria.

Building a Canadian base of survey participants was more challenging due to the fewer number of ID programs as compared to the U.S. For example, currently there are 177 accredited ID programs in the U.S. as opposed to 6 in Canada (CIDA, 2015). Rather than base the Canadian participant group solely on IDEC members or CIDA programs, I included all of the degree-granting universities listed on the Interior Designers of Canada (IDC) website. In 2013 there were fourteen institutions listed. Two additional participants were also added based on the 2014 IDEC conference based on the same criteria as the U.S. educator volunteers. The number of Canadian participants were still shy of the potential U.S. questionnaire recipient list so, as a member of the Biomimicry Educators Network (BEN), I searched for BEN members on the Biomimicry Institute website, in 2013, who met similar credentials as those Canadian educators already selected. From that research, I added nineteen survey participants that teach at Canadian degree granting institutions offering undergraduate ID course content or taught in design-related disciplines who indicated they taught BID

in their courses. Ultimately, 35 educators from each country were invited to participate in the questionnaire survey. In all cases, the invitation was emailed to each institution's Department Head, unless directed otherwise, with a weblink to the questionnaire.

2.3.2 Research instrument

The questionnaire comprised of 24 questions pertaining to the:

- magnitude of programs and courses integrating biomimicry
- course context
- delivery models
- teaching methodologies
- interdisciplinary opportunities and team building tactics
- benchmarks and milestones
- student outcomes and educator assessment tools
- advice for educators considering the integration of BID strategies into their curricula

Some of the institutions delivered courses or programs online, so the questionnaire included questions that would investigate the pros and cons of that delivery model if any. By utilizing an online survey vehicle, data was collected and organized accordingly from the U.S. or Canada separately, for analysis and comparison purposes, as discussed in Chapter 4.

2.4 Precedent Study: Biology Inspired Curricula

A study of post-secondary BID and biomimicry courses was undertaken to conclude the thesis research. Groat and Wang (2002) believe that a research component in a multilayered design study that examines real-world scenarios in detail is

important to understanding a topic's complexities in context. Goel et al. (2015) case study is a valuable learning tool in particular BID classrooms explaining, "This is because case studies situate design knowledge in authentic contexts and real practice" (p.216). Stake describes the benefit of precedent studies as "both a process of inquiry about the case and the product of that inquiry" (cited in Karpan, 2005, p.70). A precedent study has the ability to uncover overlapping factors, links, and synergies (Groat and Wang, 2002). Although a precedent study may be simply a static summary of what is as opposed to what could be, Rugg and Petre (2002) believe that it is not uncommon for researchers in a given field to reach a consensus about what is working and what is not, and providing insights in their own way.

This final phase of this thesis research, involves a precedent study of seven biomimetic design courses. The precedent study explores courses integrating BID and biomimicry from 2005 onwards. Identifying examples of how biomimicry education is evolving in design disciplines is important to understanding the mechanics, value and possibilities for its integration into ID curricula. The examples selected are the result of the research from the literature review and various websites pertaining to SD, BID, and biomimicry education and innovation. The intent of this precedent study research was to compare how educators in design-related disciplines teach BID and biomimicry to their students. The research criteria sought out examples that:

- utilize biomimicry principles, processes and/or practices
- align with ID or design-related curriculum priorities
- involve interdisciplinary skills
- exhibit teaching tools that may be employable by ID pedagogy

- consider learner education at any student level or in any context
- discuss sustainable design strategies respective to North American bioregions

In the precedent study analysis, the research sought to uncover overlaps and common threads in teaching methodologies, how interdisciplinary methodologies are integrated, as well as how limiting or expansive research studies are in North America in relation to BID education. Lastly, the analysis of this research phase sought to understand the BID motivators or inhibitors for educators and learners, unforeseen issues, and the most effective models for assessing the students and the course.

2.5 Research Data Analysis

Based on the design of the mixed-method inquiry, the data analysis took on a multitactic approach (Groat & Wang, 2002). In addition to the review of literature survey had both a questionnaire and interview component, different data analysis procedures were employed. The questionnaire was designed to primarily acquire qualitative data however in some cases those results were quantified in order to; (a) compare the number of U.S. as opposed to Canadian respondents, (b) to compare the number of the U.S. respondents in this survey against those of Angne's 2010 survey, and (c) to note any changes in the quantity of responses as the survey questions became more progressively more detailed about biomimicry. According to Sandelowski (2000), "Quantitative treatments of qualitative data can also be used to extract more information from the qualitative, and to confirm researchers' impressions from these data [sets]" (p.253). Combining content analysis tactics were utilized to compare the findings.

The anonymous questionnaire was emailed to U.S. and Canadian educators simultaneously, in two groupings, in order to analyse and compare the data by country.

By sending the questionnaires to the two countries separately, it enabled the comparison of the U.S. responses to those received by Angne's 2010 survey, as well as providing the data to highlight discernable changes in the U.S. ID programs over the four-year span (Angne, 2012; Booth, Colomb & Williams, 2008). In that Survey Monkey was the vehicle used to construct the questionnaires, this survey mechanism also collected and organized the responses for further analysis and comparison. This digital survey tool also provided the numerical calculations of the responses, which were subsequently analyzed on a descriptive statistical basis.

The questionnaire responses were scrutinized using axial coding to seek out repetitive themes, contrasts and similarities based for the key areas of inquiry pertaining to teaching experiences regarding; sustainable design, BID, interdisciplinary and collaboration strategies, and biomimicry. The data analysis looked for preferred teaching methodologies, potential cognitive challenges, and experiences pertaining to course outcomes that could be transferable to ID curricula for Canadian educators. The triangulated research design provided multiple options for comparing results, drawing conclusions, and verifying data.

The semi-structured interviews provided for deeper exploration of BID teaching experiences, to both clarify questionnaire responses unique to the respective interviewee, and investigate the implications of specific responses. The unstructured component of the interview allowed for time to discuss educator experiences that were phenomenological in nature. This casual-comparative study of interviewees from like educational settings but unique backgrounds and experiences, highlighted the differences among the interview participants, and provided the potential to reveal the

cause for contrasting survey results (Groat & Wang, 2002). The content analysis of the semi-structured interviews focussed on reoccurring themes, commonalities, patterns, and contrasting opinions that could be compared to the literature review, questionnaire, and precedent study, and add credibility to the research findings and thesis conclusions (Karpan, 2005).

A relational analysis methodology was used for comparing the approach to BID and biomimicry course curricula in the precedent study. Common categories of student make-up, structure, and teaching strategies and tools were identified. Appendix C contains a summary of the course details described in the precedent study in Chapter Four. The courses studied also chronicle the transformation of BID to biomimicry curricula from 2005 to the present time, and provide a rich resource of data in educational models for ID educators.

3.0 Literature Review Findings

The initial focus of the literature review was to learn about the evolution and the core principles of biomimicry as introduced in Chapter 2. The review of literature, in these primary areas of research, provided the broadest perspective of biomimicry as well as the criteria and the tools required for knowledge building in this complex dialogue of biology inspired design (BID). Although the research inquiry sought out Canadian studies in biomimicry education, the majority of research originated from the U.S. The amount of research available online expanded as the study progressed, as did the number of U.S. institutions integrating biomimicry into their programs. These findings indicated that biomimicry awareness in the U.S. is growing exponentially, and that Canadian educators are slower to respond to this growing ecology responsive movement. Although the literature review research was dominated by U.S. studies, studies were sourced from other countries to provide a wider ecological worldview. The following paragraphs introduce the organization of the literature review findings and describes how each section pertains to the study

Section 3.1 "*Nature as Model*, *Nature as Measure, Nature as Mentor"* represents the key lessons that nature teaches according to Benyus (1997, epigraph). This section describes how the research findings relate to these themes and discusses utilization strategies, stakeholders, and concepts for measuring the outcomes when integrating biology into ID problem-solving methodology. Global perspectives from biomimics, practioners, scholars and educators, regarding ecological literacy, evolving synergies, transformative theory, and biomimicry applications that contribute to sustainable design initiatives in an ID context are also explored.

Section 3.2 Exploring BID Strategies in Design Education provides a synopsis of how biomimicry is taught at institutions of higher education. It reviews the various educational approaches and challenges explored, including a cross-section of the teaching methodologies and tools. This section of the literature review also researched the cognitive and practical challenges in teaching biomimicry, and strategies to overcome them.

The next section of the literature review is Section 3.3 Delivering ID Education. The review of literature presented in this section pertains to: program accreditation criteria; teaching methodologies; creativity; the learner environment; curricula; and learning theory as it relates to interior designers' BOK.

Section 3.4 Challenges to Teaching Biomimicry is an overview of the challenges and controversy surrounding the integration of BID into non-science based disciplines. This section discusses what academics believe to be the primary challenges in teaching in a multidisciplinary context, and concerns educators have when introducing complex new topics into their curricula.

Lastly Section 3.5 Observations, is the conclusion of the literature review, summarizing the findings and providing observations from the data collected. It provides a synthesis of the key biomimicry concepts, and assesses their value to ID education.

3.1 Nature as Model, Nature as Measure, Nature as Mentor[2]

3.1.1 Nature as Model

"Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems" (Benyus, 1997, epigraph).

In the last century, it has become evident that without intervention, our natural resources will not sustain generations to come. Manufacturing processes have historically disregarded the fragility of our ecosystems. A shifting worldview is favouring collaborating with nature as opposed to dominating it. Biomimicry advances the concept of weaving nature's SD strategies into our manufactured world, using lessons from nature to solve human problems in a less detrimental way. Educators may perceive that teaching biomimicry requires a comprehensive understanding of biological processes and their applications in various contexts, hence it would be a complex topic to teach, comprehend, utilize and evaluate in non-science based applications. This study endeavours to understand if this is a key impediment to why biomimicry has been slow to integrate into Canadian ID curricula.

Biomimicry is a multi-faceted process involving various disciplines and a deep scientific premise. The concept utilizes a multidisciplinary methodology to solve problems that includes expertise in business and finance, biology, and design, architecture and/or engineering. Crossing disciplines and widening the stakeholders adds more layers to an already multi-layered problem-solving process.

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[2] Benyus (1997, epigraph) in *Biomimicry: Innovation inspired by nature* discusses what nature can teach us.

Benyus' book *Biomimicry: Innovation Inspired by Nature* is the cornerstone of the current BID movement. Since the book's publication in 1997, additional research has supported BID theory, including the creation of the Biomimicry Institute. The guiding principles are 'nature as model, nature as measure, and nature as mentor' according to Benyus (1997, epigraph). Benyus believes that biomimicry or the mimicking of biology can restore a human-nature balance and begin to repair ecological damage. A transformative worldview that challenges mainstream socio-economic norms. It is much easier to throw something in the trash than to recycle it. This practice disregards the earth's natural ability to restore itself, and builds mountains of garbage that could take millions of years to biodegrade. The construction industry is a major contributor of waste in landfills not to mention the pollutants emitted into our air, and leach into our waterways (Moxon, 2012). Interior designers rarely consider the deconstruction of their projects during the design development process. Biomimicry has a variety of benefits to interior designers and the indoor environment they create.

Although biology inspired concepts for problem-solving may seem unfamiliar to designers, Steffen (2011) in the book *Worldchanging: A Users Guide to the 21st Century*, reminds us that although nature is not perfect, "everything we see in nature has been field-tested for thousands or millions of years "(p.99). Steffen's encyclopaedia of green ideas includes discussions and action plans for advancing environmental sustainability, illustrating how biomimicry borrows protocols from nature to teach humans about regenerative practices. Application strategies are the strengths of the Biomimicry Institute, and in addition to connecting learners to state-of-the-art BID

research, it provides a program of education, teaching support, and tools to understand and apply nature's lessons.

Long before Benyus (1997) coined the term biomimicry, the book *Silent Spring* (Carson, 1962), became a precedent for environmental awareness and protectionism. Carson, a marine biologist, contracted cancer after years of living between two waterways in the Pittsburgh area poisoned by toxic by-products industrial waste (Lear, 2002). *Silent Spring* reinforced the fragile link between ecology and the technological evolution spawning the need for environmental education and design awareness. According to E.O. Wilson (2002), Carson "delivered a galvanic jolt to public consciousness, and, as a result, infused the environmental movement with new substance and meaning," (p.358) as noted in afterward of *Silent Spring* (Carson, 2002). Carson's personal war with chemical toxicity in the environment heightened public awareness, and she successfully lobbied the government for legislation prohibiting manufacturers from such practices. Carson's efforts were long lasting and in 1970 led to the creation of the United States Environmental Protection Agency (EPA), and eventually World Environment Day in 1972. This increase in public awareness contributed to the banning of DDT in the U.S. in 1972 for agricultural use.

Environmental awareness continued to gain traction, and 1972 saw the formation of the Deep Ecology movement. This ecological fundamentalist group, founded by Arne Naess, an advocate of Carson, offered a platform for discussions regarding ecology connective philosophies. Their website blogs provide thought provoking theories, and a database of research and education in everything ecological (Space and Motion, 2011). In 1987, the Brundtland Report, produced by the World Commission on Environment

and Development [WCED], proclaimed that sustainable development was instrumental to "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Foidart, 2010, p.69). Rachel Carson did not survive to see her book published, however "Carson sent an important warning to the world" (McDonough & Braungart, 2002, p.149), and her contributions toward environmental awareness and protectionism endure (Figure 3).

Figure 3: Google's homage to Rachel Carson on her 107th birthday
(Google, 2014). Google and the Google logo are registered trademarks of Google Inc.
(Used with permission.)

Just as the book *Silent Spring* was gaining attention, Buckminster Fuller was in the process of presenting numerous papers discussing how environmental issues affected the built environment. In 1964, *The Design Initiative*, Fuller discussed how essential the collaboration between nature, science, technological design is conceptualized in his spaceship earth[3] theory. Fuller believed strongly in the benefits of BID and used tensegrity, the lightweight design concept mimicking dragonfly wings, for the structural design of his geodesic domes (Benyus as cited in Kellert, Heerwagen & Mador [Eds.], 2008). E.O. Wilson furthered these concepts of our human-nature

[3] *Operating manual for spaceship earth* (Fuller, R. B., & Snyder, J., 1969) discusses Fuller's theory of treating earth's ecology as a limited resource as if an aircraft and humans are the astronauts' responsible for its care and maintenance

interdependencies in *The Diversity of Life* (1984) theorizing that a non-traditional multidisciplinary approach is a key to biodiversity in the built environment (Kellert and Heerwagen, 2008).

Benyus (Kellert ed., 2008) acknowledges that biomimicry is not the first biology inspired design strategy to understand the value of applying nature's principles to human problems. According to Benyus, Hale (1994) postulates that early Greeks looked to ecology for inspiration believing that utilizing "nature's math" would close the gap between humans and the universe (as cited in Kellert et al. [Eds.], 2008, p.28). Biomimicry provides an action-oriented process that provides a framework for design teams to achieve repeatable outcomes, where every solution has infinite lifecycle potential. This sustainable design strategy is described in detail by the Biomimicry Institute fellows and the authors of *Cradle to Cradle – Remaking the Way We Make Things* (McDonough & Braungart, 2002). Simply put, McDonough and Braungart distil their recycling model as "waste equals food", a closed loop philosophy that challenges the design and manufacturing worlds to construct within (p.92) (Figure 4). In the 'Technical Nutrients' loop designers play key roles in the evolution of each phase, and possess the power to make sustainable choices once informed.

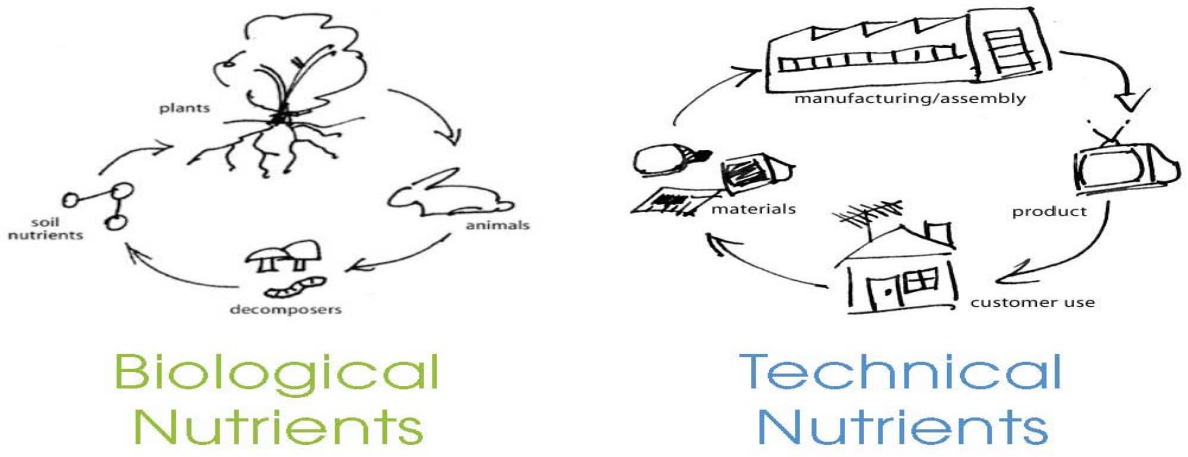


Figure 4: Biological nutrients vs. technical nutrients (model for regeneration)
(Cradle to Cradle Products Innovation Institute, webinar September 24, 2013.
Used with permission.)

Based on my literature review, the restoration of the human-nature connection has accelerated exponentially in recent years. If my resulting research is an indication of biomimicry progress, approximately 95% of my sources were dated from 2000 onwards, and 75% of that research originated from studies dated 2010-2014. Chambers (2011), in her thesis research, illustrated her U.S. findings of how biomimicry research and patents had climbed since 2000 in Figure 5.1 & 5.2.

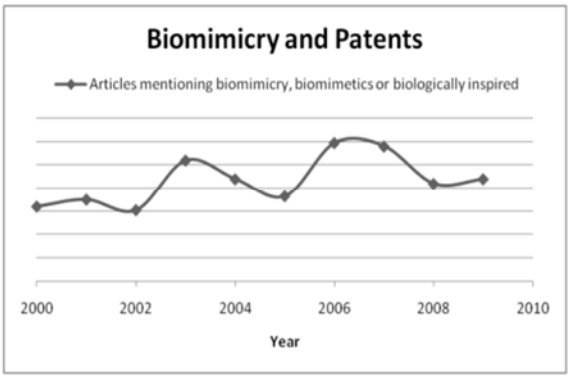


Figure 5.1: Biologically-inspired Patents
(Chambers, 2011. Adapted from Bosner, 2006.
Used with permission.)

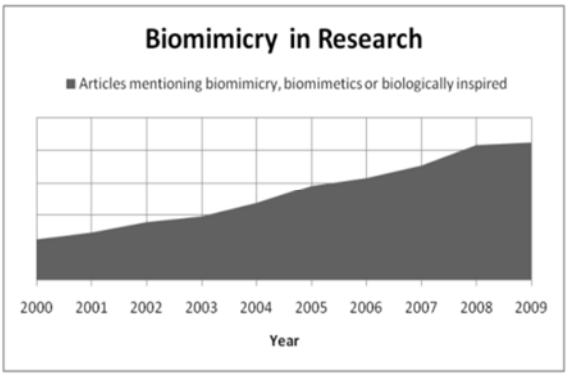


Figure 5.2: Biologically-inspired Research
(Chambers, 2011. Used with permission.)

Bosner and Vincent claim that nature-inspired patents and research has grown exponentially in the last generation (cited in Goel et al., 2015). Not only has the quantity of biomimicry related patents in the U.S., and research studies steadily increased in recent years, but so too has the number of organizations supporting biomimicry themes at conferences. Biology inspired design 'innovation challenges' have evolved to advance the research and development of biomimicry applications engaging and connecting students, educators and practioners from design-related disciplines, including ID, globally.

Biomimicry provides expanded opportunities in the built environment for interior designers on sustainable project teams. BID principles and processes proved invaluable in the design of a healthcare facility in Massachusetts, unifying users with the built environment as described in Michael Maglic's 2012 practicum paper. This study illustrates how biomimicry informed the project's design development holistically from site planning through to finished construction. One of Maglic's early but key design decisions was the utilization of a human bone methodology. Through his research he learned how structurally beneficial the bone physiology could be as a shield to protect the structure from the extreme site conditions (the site was exposed to water on three sides and have no natural protection from wind or snow loads). The cell structure not only served as the premise for the building skin and structure but also provided portals for daylighting that in turn added to the textures of the ID (Figure 6). Computer modeling was an essential tool in visualizing the integration of the functional priorities and the aesthetic requirements of a user-friendly healing environment. As Maglic

(2012), Kellert (2008) believes that BID reconnects humankind with nature, particularity pertaining to the built environment.

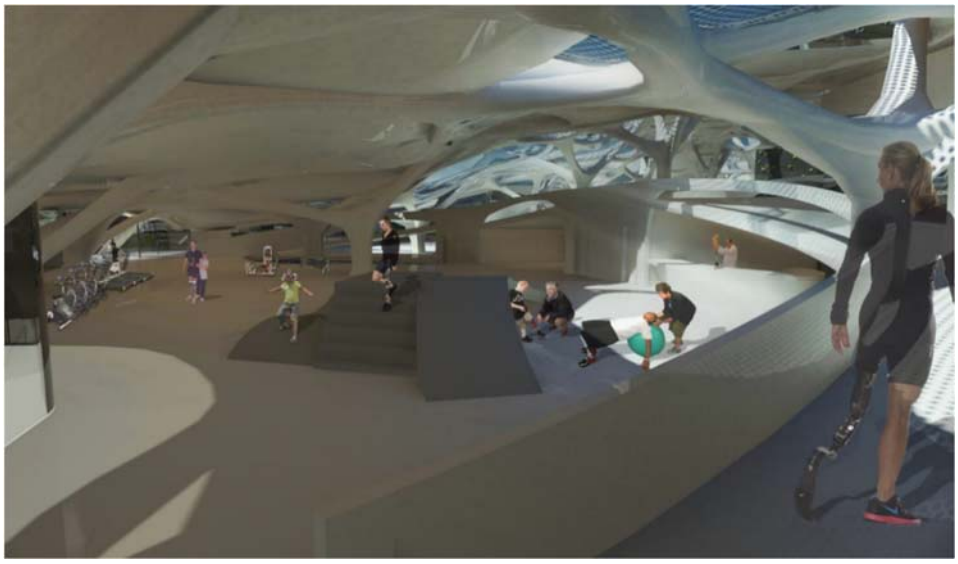


Figure 6: Model of Therapy Room
(Maglic, 2012. Used with permission.)

Industrial designer, Joris Laarman, took inspiration from the human bone when he created the Bone Chair (Figure 7) that gains strength using the bare minimum of material according to Benyus (Kellert ed., 2008). This is another example, when exploring design solutions through a biological lens, of how function and aesthetics can work in concert with when adopting biomimicry approach.

Figure 7: Bone armchair designed by Joris Laarman
(Photo retrieved from http://www.designgallerist.com/joris-laarman-bone-chair. Used with permission.)

Biomimicry has influenced more product developments than many realize. Velcro is a better know example of a product modeled after nature. The scratchy side resembles the 'hooks' that burrs use to attach to other objects for transportation for their next seed disbursal and germination location (Steffen, 2011). This database tool requires the designer to ask 'how would nature' solve a human problem, defined by a process in nature, i.e.: utilize, limit, control, maximize, extend, etc. To assist designers in understanding and better utilizing BID utilization strategies, the Biomimicry Institute designed the Biomimicry Taxonomy chart (see Appendix B), which provides an index of biological processes that organisms and natural systems utilize to guide the problem-solving process. Using this taxonomy of functions, questions applied to the AskNature database tool, deliver a design inquiry response. Utilizing the Biomimicry Taxonomy chart and the AskNature database, I constructed a chart (Figure 8) to illustrate the problem-solving methodology as it progresses from design challenge, to biological strategy, to design application in the interior environment. Through the use images to express both the biological organism and the finished product, this chart illustrates examples of how to: utilize chemical free pigments, reduce material maintenance, control light and capture energy, maximize functionality with minimal materials, limit waste of materials, improve human health, and program the space for the end user.

Biomimicry provides inspiration to design disciplines in a variety on contexts. It has proven to be a powerful methodology for the control of infection, a serious concern in healthcare and food service environments, and places where human hygiene is critical. Sharklet Technologies in the U.S. have studied the anti-microbial properties of sharks' skin and developed a protective coating for high-touch surfaces for example,

door hardware, millwork and counters, and light switches (Hennighausen & Roson, 2013). This coating repels bacteria, and is a revolutionary step in inhibiting the spread of disease from person to person. Infection control practices received global attention for all concerned with advent of the Sever Acute Respiratory Syndrome (SARS) outbreak of 2003. "Globally, 20 percent of confirmed SARS cases were health-care workers. In Canada, healthcare workers made up 43 per cent of SARS cases," according to Branswell (2013, p.2). Wearing protective gear was one of the few but effective actions the workers employed that eventually vanquished the SARS's coronavirus, notes Branswell in her article for The Canadian Press. Considering that one single cell can multiply into 8 million in less than 24 hours, according to Sharklet Technology's research, infection control is a maintenance priority at critical care facilities. When cutbacks occur, housekeeping budgets are often compromised in my healthcare project experience. Sharklet Technology's biology inspired microorganism-resistant film could become the most significant advance in infection control today. The question "how would nature do it?" is the guiding principle in utilizing biomimicry according to (Benyus, 1997; El-Zeiny, 2012). Although a relatively new theory in practice, there is growing evidence that biomimicry affords a feasible process for design professionals.

HOK, the design and architectural firm with offices across North America, known for its multi-disciplinary project team approach is also a supporting member of the Biomimicry 3.8 organization. HOK utilizes Life's Principles in their biomimicry practices and publishes their experiences in the *Genius of Biome* report.

Utilizing Life's Principles using **AskNature tool**: how would nature …

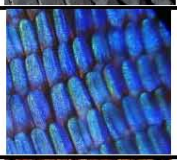
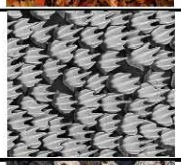
Design challenge	Example of biological strategy		Design application
Utilize chemical free pigments?		Morpho butterfly: wing construction refracts like to emmit virtual colour which inspired the development of Morphotex fabric (Teijin Fabrics)	
Lower material maintenance?		Lotus leaf: study of large-winged insects and plant surfaces ispired the development of Lotusan Paint a self-cleaning paints	
Control light and capture energy?		Tree leaves: the way plants maximize exposure to sun to maximize photosynthesis by moving throughout the day inspiring Solar Ivy (SMIT) panels that move with the sunlight	
Maximize functionality with minimal materials?		Natural forming patterns provide a myraid of interior uses: pattern, shadow, light diffusion, accoustic control, space division	
Extend material life?		Animal and vegetable wing/skin/coatings: the water repellent qualities inspired Nano-Sphere (Schoeller Technologies) fabric finish that repels dirt and stains	
Limit waste?		Forest floor functionality: aesthetic design and regenerative c2c strategies became the norm for Entrophy carpet tiles (Interface) greatly reducing carpet installation waste	
Improve human health?		Shark skin: the anti-microbial properties of this fish inspired the Sharklet Surface Protection film (Sharklet Technologies) inhibit bacteria growth on high-touch surfaces	
Program space?		Sessile barnacle: space utilization could be inspired based on their ability to optimize space where physical habitat is limited when the barnacle population density increases	

Figure 8: Examples of biomimicry utilization strategies for interior designers
(chart by author; photographs used with permission)

King (2012) notes that Thomas Knittel of HOK believes that biomimicry provides "inexhaustible inspiration" to their LEED projects adding it brings "a recursiveness that is needed in a normally linear process" (n.p., paragraph 5). Knittel states that "designers

may have an easier entry point because we are already trained in ideation, are constantly seeking precedents, and look for horizontal transfer of ideas from other disciplines" (n.p., paragraph 6). The biomimicry process is highly dependent on the designer's ability to communicate and mold an idea into an object of desire for consumption. Although this may not be a unique assignment for a designer, it is an essential biology inspired design principle (Benyus, 1997), as a science-based solution may not be perceived as desirable or having consumer appeal in the marketplace.

As interior designers learn to involve biology inspired design (BID) strategies into problem-solving, they will deepen their understanding of regenerative design and how they can have a positive ecological impact on the environment. Sherwin (2013) supports this theory in his article for the Ellen MacArthur Foundation entitled Design Matters: for the Circular Economy, and refers to the relationship between objects and consumers of the future. He believes that designers, as critical team members, will be integral not only in the creation and construction processes, but in the disassembly of the finished product as well (Sherwin, 2013). Coleman (2015), in her discussion on the future vision of ID, notes that when educators help students to expand their awareness of and responsiveness to cultural concepts such as environmental stewardship, it will empower designers and heighten "design relevance" (p.xiii). Biomimicry could be the mechanism that bridges the boundaries that divide the disciplines on integrative project teams, and provides a democratic platform for interior designers to contribute with equally valued expertise (Poldma, 2003; Sorrento, 2012; Wang, Vaux & Xu, 2014).

3.1.2 Nature as Measure

"Biomimicry uses an ecological standard to judge the rightness of our innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts." (Benyus, 1997, epigraph).

Measurements in nature are essential to its existence and evolution, according to Darwin's theory of natural selection where only the fittest survive the rigor of ecological development (O'Neill, 2014). Benyus believes that biomimicry is a solution-seeking process that provides three key measurement categories for designers to consider: form, process, and ecosystem (Kellert, 2008). Different practitioners measure the core characteristics of BID in different ways. Moxon believes that with evidence of rigor, such as measuring tools, in SD utilization strategies there will be a lessened perception of 'green-washing', the notion that all sustainable strategies are considered 'green' and of equal importance (Moxon, 2012).

Michael Ben-Eli (2006) of the Cybertech Consulting Group Inc. believes that to advance order and provide rigor socio-economically sustainability standards require accountability. Ben-Eli's theory of measuring sustainable feasibility, inspired by R. Buckminster Fuller, sets out the following value framework consisting of when: The Material Domain; the Economic Domain; The Domain of Life; The Social Domain; and The Spiritual Domain (Ben-Eli, 2006, p.2). His paper details how each domain acts, affects the other domains, and in turn affects the sustainability of the design decision. Although multi-layered, Ben-Eli's underlying principles include measurement concepts that interior designers could consider when evaluating the ecological impact of their projects. When preparing a life cycle cost analysis, Ben-Eli suggests, "performance

leasing" (the concept of managing the lifecycle of durable goods) as a consideration when developing design specifications. Examples in an interior environment would be lighting, doors or door hardware, which, has long term value and therefore could be reused by multiple users or recycled, increasing its value as opposed to wall covering which is disposed of when walls are demolished. Ben-Eli warns, however, that it is necessary to employ a system for the item's ongoing monitoring and maintenance through the cycles of users, which is challenging but essential. Performance leasing is an important measurement concept for designers when applying these domains in their project construction, and is the one that keeps them in balance (Ben-Eli, 2006).

A measurement tool best used to introduce biomimicry thinking is the Design Lens, a biological filter developed by The Biomimicry Institute (Figure 9). According to Benyus (2009, n.p.), this design-oriented checklist challenges the user to filter their ideas through this biological lens and ask themselves:

- Is it safe for bodily tissue?
- Does this action create conditions conductive to life?
- Is it well adapted to life on earth over the long haul?

These questions remind biomimics to recognize the interconnections and interdependencies that have developed though evolution amongst the species, and provide collaboration strategies for designers. According to the Biomimicry Institute, "By learning from these deep design lessons, we can model innovative strategies, measure our designs against these regenerative benchmarks, and allow ourselves to be mentored by nature's genius using Life's Principles as our aspirational ideals" (biomimicry.net).

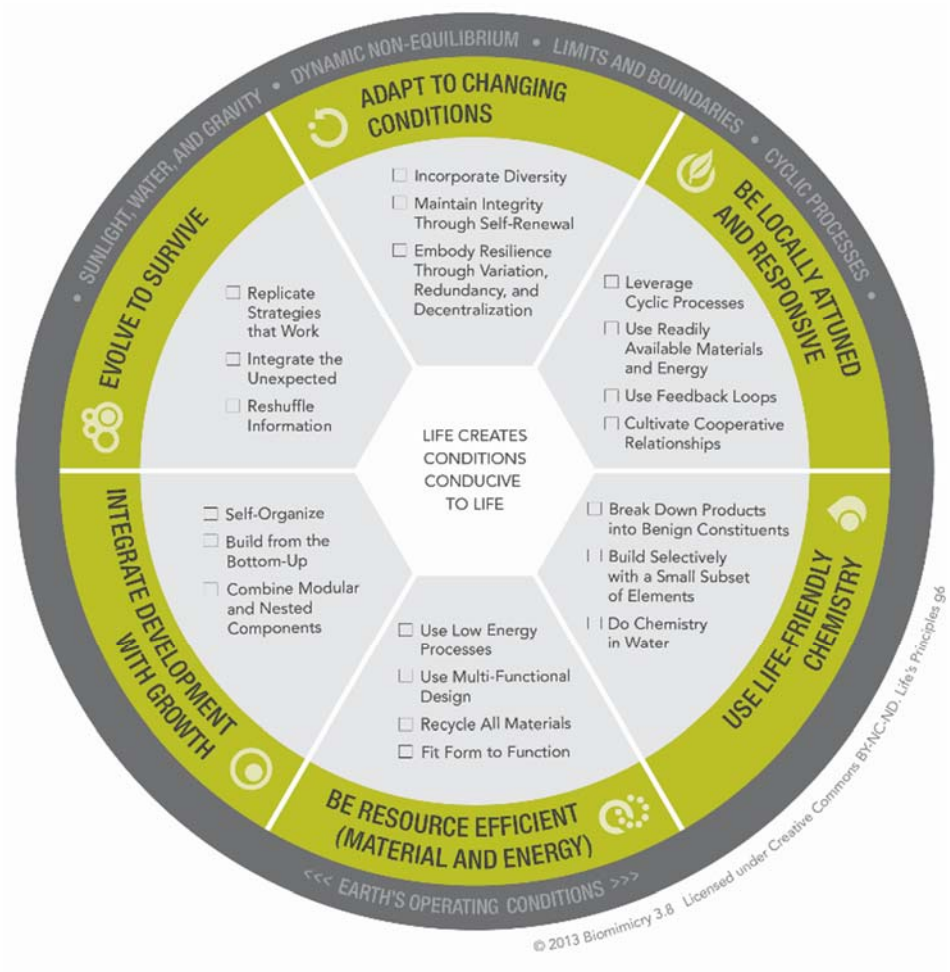


Figure 9: Life's Principles. Design Lens
(Biomimicry.net. AskNature.org. Used with permission.)

Measuring sticks provide a methodology to monitor performance and develop benchmarks. They are quantifiers in evidence-based design research, adding rigor, providing focus, and contribute to repeatability; an essential ingredient to the biomimicry process. A current measuring stick for sustainable buildings is the rating system known as LEED. Although criticized for its quantitative approach to sustainable design, the newest version of LEED, version 4 (CaGBC, 2013), now recognizes the importance of process, and rewards design teams with process-based and regenerative design credits. LEED offers both a structure and a mechanism to measure the outcome. Since

the inception of LEED, there are a number of accounting tools emerging to valuate eco-successes, such as Corporate Ecosystem Valuation (CEV) systems.

The C2C Certification Multi-Standard (Figure 10) is a valuable tool developed by the Cradle to Cradle Products Innovation Institute. According to the institute website, the five categories in Figure 10 are the qualities assessed when manufacturers submit products for certification. Products are tested every two years by a qualified independent organization, once approved based on the evaluation criteria.

Figure 10: Cradle to Cradle Certification Multi-Attribute Standard
(Cradle to Cradle Products Innovation Institute, 2013. Used with permission.)

The five product assessment standards that provide benefits to the environment as defined by the Cradle to Cradle Products Innovation Institute are:

- Material health: Knowing the chemical ingredients of every material in a product and optimizing towards safer materials.
- Material Reutilization: Designing products made with materials that come from and can safely return to nature or industry.
- Renewable Energy: Realizing a future where all manufacturing is powered by 100% clean renewable energy.
- Water Stewardship: Manage clean water as a precious resource and essential human right.

- Social Fairness: Design operations to honour all people and natural systems affected by the creation, use, disposal, or reuse of a product.

Certified products are available online through a search tool providing a valuable resource of materials for the designers' during the selection and specification process. The Institute has become an affiliate member of the Ellen MacArthur Foundation, an organization based on the concept of circular economies. "A circular economy is one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and quality at all times, distinguishing between technical and biological cycles" (Ellen MacArthur Foundation, n.d.) This foundation considers its program an important link between earth-friendly materials and cradle-to-cradle design initiatives. Cradle to Cradle Products Certification Program registry assures designers, their clients, and the public, that the products listed have undergone rigorous testing, and are safe for the environment today and for the future. C2C certification not only raises the bar for manufacturers, but also heightens consumer awareness. It makes one take pause in their purchasing practices to consider the humanly safety and/or environmentally 'green' factors of a product.

Two of the most aggressive targets to accelerate and measure sustainable design outcomes are the Living Future Institutes' initiative, called the Living Building Challenge (LBC) 3.0 (LBC, 2006), and the 2030 Challenge (Architecture, 2010). The LBC measures the eco-success relating to social justice and material nutrition as well as energy efficiency, whereas the 2030 Challenge targets quantitative outcomes for buildings to become carbon-neutral (operating without the use of fossil fuels or greenhouse-gas-emitting energy) by 2030. The most current LBC v4 is the most

comprehensive and holistic challenge of on a global scale created to date (Living Future Institute, 2014). The LBC believes it is for this reason that "it satisfies our left brain craving for order and thresholds, and our right brain intuition that the focus needs to be on our relationship and understanding of the whole of life" (Living Building Challenge v3, p.6). The LBC's initiatives are inherently qualitative and include equity, access to nature and place, beauty and spirit, and inspiration and education.

3.1.3 Nature as Mentor

"Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can *extract* from the natural world but what we can *learn* from it" (Benyus, 1997, epigraph)

Biomimicry offers billions of years of lessons from nature to guide humans in their problem solving. Van der Ryn & Cowan (2007), in their book *Ecological Design*, claim "design problems like these bridge conventional scientific and design disciplines. They can be solved only if [industrial] designers talk to bio-geochemist, sanitation engineers to wetland biologists, architects to physicists, and farmers to ecologists" (preface). Biomimicry not only provides a process but an interdisciplinary necessity for design teams that will "… mirror nature's deep interconnections [designing less as a machine] and more in a way that honors the complexity and diversity of life itself" (preface, p. xi). Organizations like Sustainable Brands (SB) believe that a collaboration spirit is essential in the transformation toward BID innovation. Coca (2013) suspects that the Integrative Design Process (IDP) originated as a response to Brundtland Report (1987) in the attempt to embrace sustainable design in a holistic, proactive manner. Coca describes IDP as a "discovery process" which is essential to connect a design team that involves a

human-nature connection (p.6). Coca adds that "Collaboration is an offer of a complete altruism, respect for the expertise and opinions of all participants, and acceptance that the thinking process has to alter" (p.58), but notes leadership is key. IDP is a design team strategy for problem–solving when multiple disciplines must work together to develop solutions for complex problems. Verbeek (2011), a Biomimicry Institute Education Fellow, stresses the importance of this teaming philosophy as well, observing that "Interdisciplinary collaboration across traditional silos such as department, faculties and professions is increasingly required to generate creative and innovative solutions in today's complex world" (p.1).

McGregor (2013) believes that the aspect of transdisciplinary is also a concept worth considering when employing biomimicry in solving human problems. Transdisciplinary integration integrates various perspectives and knowledge, interjected with biomimicry insights. McGregor enlightens the discussion with a 'Logic of the Included Middle' consideration whereas transdisciplinary problem solving values the ground in between nature and human, and involves the ability for the design team to adapt, deconstruct and rebuild as may be required (p.63). Regardless of the terminology, biomimicry allows for a fluid and cooperative human-nature relationship that continues to evolve.

My literature review sought out research that studied transformative strategies that addressed what is required to deliver the biomimetic knowledge as a regenerative design tool to interior designers. How does this change occur is the question that practitioners and educators ask, and where does this new knowledge originate? Tony Fry (2009), a consultant in sustainable practices, educator and author of *Design*

Futuring, believes designers bear a responsibility in actively embracing regenerative design and challenges educators to graduate biomimetic-informed designers. However, he does not deny that professionals need to lead their project teams towards advancing their sustainable design expertise. Fry insists that the 'redirective practice' needs to "deliver a continuous learning environment" without exception (p.126).

Another practitioner, design-architect Bruce Mau (2005), expresses concerns for the environment in his book *Massive Change* and suggests guidance and resources for change. In his book, Mau uses the example of the Montreal ice storm (Figure 11) where a devastating ice storm destroyed hydro pylons and left the city without power for weeks to express the importance of a stronger human-nature connection in design. Mau uses this photo to reinforce his belief that "For most of us, design is invisible until it fails", (Figure 11) (Mau, 2005, n.p.). Mau reinforces his ecological design theories through his firm's global project work delivered by interdisciplinary teams, which include expertise from business, engineering sciences and all facets of the design community. Collaborative project teams result in a more ambitious collective synergy, but never underestimating the value of design (Mau, 2005; Sorrento, 2012).

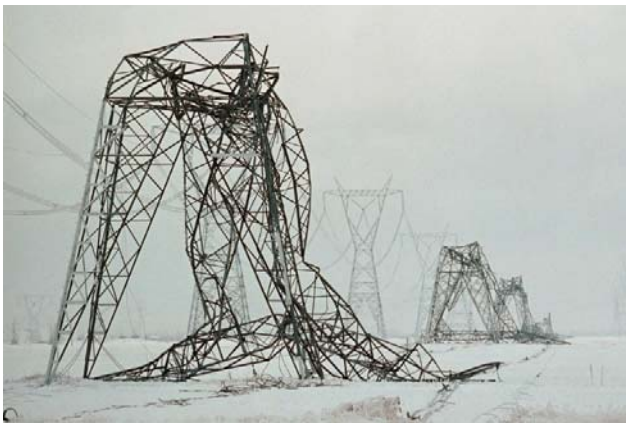


Figure 11: Hydro pylons bend and break from weight of ice during Montreal ice storm (IceStorm, Robert Lebarge photographer, 2005. Used with permission.)

By utilizing biomimicry principles, nature guides humans towards regenerative strategies in a mechanized world (Benyus, 1997). Reed (2007) believes that for disciplines responsible for the built environment to reconnect with the "web of life", a Whole Systems and Living Systems Thinking is required (p.675). In the paper, Designing From Place: A Regenerative Framework and Methodology, Reed describes whole systems thinking as a process to link mechanistic to ecological consciousness. From this awareness, a living systems approach considers the restorative and regenerative processes in nature, and applies them to the human condition. These processes, described by Reed (2007), translate into a paradigm shift of worldview that acknowledges that all living things are not only interrelated but also interdependent. The design process needs to include investigations beyond the technical aspects of sustainability, for example rating systems. Disciplines responsible for built environments need to consider the life-enhancing values and end-of-life consequences of their design and material decisions. From his research, Reed proposes strategies to facilitate this transition in design disciplines, discussed further in Chapter 5.

3.2 Exploring BID Strategies in Design Education

The infusion of biology into design education is not a new idea however not until twenty-first century have studies researching BID in education become as readily accessible, largely due to the internet. This literature review sought out the key strategies that educators are currently using most often to facilitate the integration of science-based concepts into design-based courses.

3.2.1 Systems Thinking & Design Patterning

Stave and Hopper describe systemic thinking as the "cognitive processes that: see relationships rather than things; cause-effect relations as reciprocal; multiple causes/multiple effects; and system structures that have cause system behaviour" (as cited in Sosa, Dorantes, Cardenas & Martinez, 2010, n.p.). Systems thinking, sometimes referred to as 'design-thinking' or 'systemic thinking', is a highly valued problem-solving concept in sustainable design pedagogy. It is a methodology that many theorists agree is an important strategy to employ in approaching BID, and Sosa et al. (2010) believe it is essential when approaching complex problems (Figure 12).

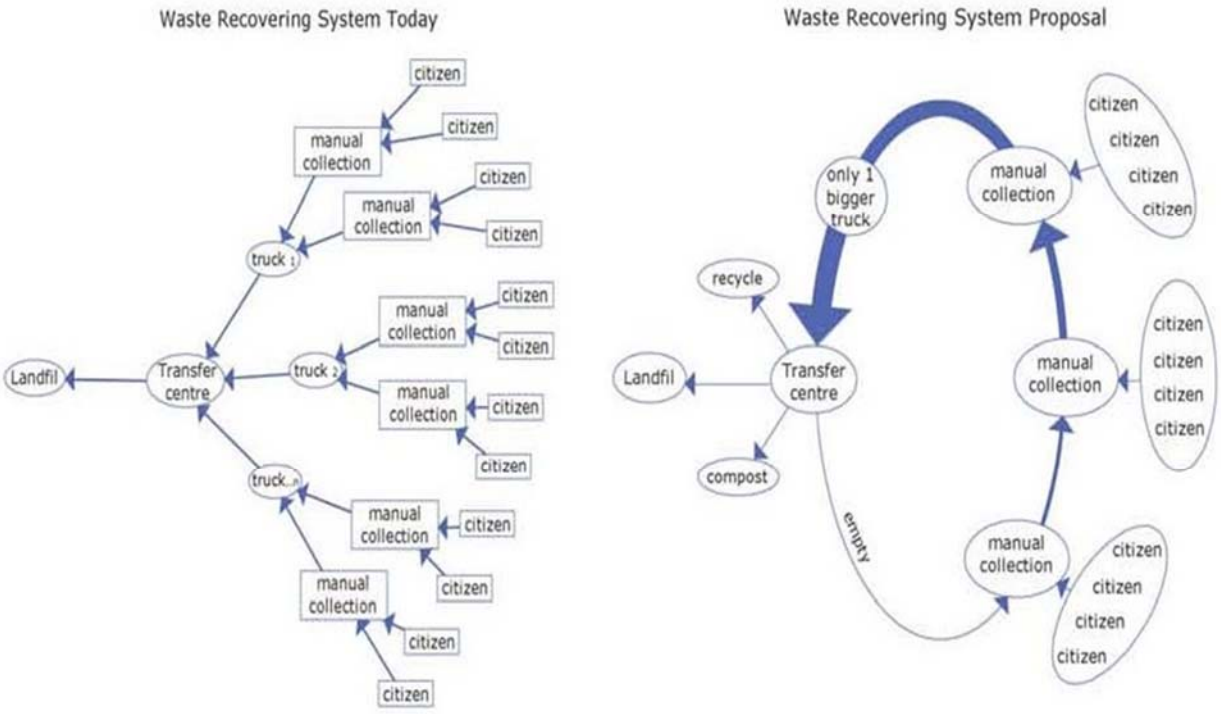


Figure 12: How systems thinking can promote a paradigm change (solution-driven vs. process-driven) (Sosa et al, 2010. Used with permission.)

Some BEN educators teach systems thinking in their university curricula, believing that it best reflects nature's problem-solving strategy (McNamara, 2012). The

students who grasp systems thinking at the highest cognitive level “aim to develop new strategies, models, and policies that trigger sustainable paradigm changes” (p.3). One concept utilized in systems thinking is design patterning (Figure 13). Design patterning is evolutionary within a predetermined framework, and can aid BID design teams in aligning design with patterns occurring in nature. AskNature is an excellent example of such a design pattern library. Pauwels, Hubscher, Bargas-Avila and Opwis conclude, “This database allows pattern language to be used as a prescriptive tool for application design” (p.461), and provides opportunities for design teams to think deeply and critically about how natural systems can influence problem-solving in SD contexts. Based on a case study in human-computer interaction (HCI), design patterning is a language that describes a potential solution to address recurring design problem-solving (Pauwels et al., 2010). Pauwels et al. used the design patterning methodology to structure and record knowledge for repeatability as illustrated (Figure 13).

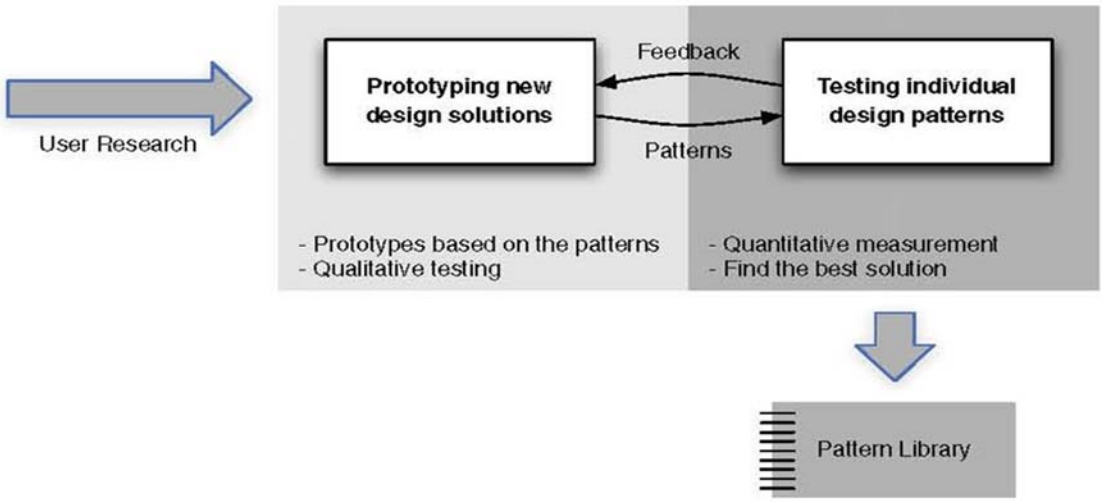


Figure 13: Alternating phases of pattern development and testing
(Pauwels et al., 2010. Used with permission.)

Design patterning is a co-creative process best utilized when integrated into a pattern library database, and aids the development of a natural language research tool. Pauwels et al. cite three fundamental examples in design pattern strategies outlined by Van Wellie & Van der Veer (2003): (a) aggregation - a design pattern can include others that complete it; (b) specialization - one design pattern is customizable once derived from another design pattern; and (c) association - multiple design patterns can occur in the same context or solve similar problems. Besides enforcing repeatability, important to the utilization of BID practices, design pattern libraries provide a visual tool that crosses disciplines for IDP teams.

3.2.2 Tools

Educators admit that biomimicry is a complex subject to teach, and for their students to comprehend and apply. Although developed for other disciplines, some teaching tools have value for ID educators. There have been various attempts to develop a databank of centralized science-based and technical knowledge intended to inform and assist in creative problem-solving. Researchers agree that streamlined tools are required to assist designers to understand and utilize BID (Chambers, 2011; McNamara, 2012; Biomimicry 3.8, 2013).

Design by Analogy to Nature Engine (DANE) was a computer-based tool developed in 2009, as a knowledge-based version of AutoCAD combining Cognitive + Collaborative + Conceptual + Creative to teach how biology (and complex systems) can assist in solving BID challenges. Introduced to undergraduate students at Georgia Institute of Technology's Centre for Biologically Inspired Design (CBID), DANE uses a functional modeling approach represented a functional modeling system to explain

biological processes utilizing a variety of visual references (Goel, 2012). Through ongoing assessment, DANE utilization highlighted the importance of efficiently delivering complex biological information to non-biological disciplines. This digital library created a "marriage of cross-domain analogies" to enhance sustainable design problem-solving (Goel, Helms, Vattam & Wiltgen, 2012, p.897). DANE remains a publicly accessible interactive tool for learning about biological systems, although CBID students access a variety of digital knowledge services according to Professor Goel (personal communication, November 25, 2015). The Web of Science is a key resource for their BID students according to the CBID Director, Professor Yen (J. Yen, personal communication, November 27, 2015).

Chambers also believes that shared computer databases are important, if not essential, in the collection, organization, and dissemination of BID for interior designers (Chambers, 2011). Chambers' thesis research describes a biomimicry database geared specifically to ID students using a Microsoft Excel spreadsheet. It is an inventive attempt to produce an ID-specific methodology for integrating natural theories into design. As an ID practitioner, a common language between disciplines defining terms and protocols would have been a valuable tool to enhance my IDP experiences.

The Biomimicry Institute website and AskNature database provides comprehensive tools to organize and disseminate state-of-the-art biomimicry research and education to practitioners, educators, and students. These resources include books, articles, lesson-plans for educators, video clips (Biomimicry Nuggets), NetLogo (a modelling tool), case studies, and a variety of related TED talks. In 2008, Biomimicry 3.8 took on the challenge to develop a shared database and launched AskNature.org,

an online tool of biological strategies to promote and inspire BID innovation (Biomimicry Institute.org). AskNature, a research database library, describes a collection of strategies:

- managing water
- life-friendly
- chemistry of nature
- green chemistry innovations (products)
- cooling down in the heat
- managing energy
- staying warm in the cold
- rainforest habitat
- retrofit

To further advance the utilization of the biomimicry database, the Biomimicry Taxonomy chart illustrates how biological functions are organized (Biomimicry 3.8 Institute, 2013) (see Appendix B). As discussed in the Literature Review, Chapter 2, the taxonomy chart introduces biological processes and compliments the Biomimicry Institute's AskNature database. The chart illustrates the strategies of how and why an organism 'acts' to produce a specific outcome. The chart outlines three approaches:

- using verbs – how would nature … collect water?
- using concepts – how would nature … manage water movement?
- using ideas that reverse verbs – how would nature … repel water?

Aligned with AskNature, BEN was created by the Biomimicry Institute. BEN, a network of biomimicry educators and an education portal for learners and educators, hosts a collection of biomimicry reference tools, including:

- reading materials
- film and discussion guides
- interactive activities; in situ experiences
- webinars
- case studies

The BEN website also offers various curriculum guidelines and teaching tools, such as the Design Lens, Life's Principles, and Design Spirals. According to my research, studies show that educators introduce Life's Principles, as well as other resources from the Biomimicry Institute's website, early in their biomimicry courses to teach BID concepts (McNamara, 2012; Sullivan, 2011).

3.2.3 Problem-solving Strategies

Complimentary to the advancement of biomimicry teaching tools is another perspective in approaching complex sustainable design challenges. Chambers (2011) in her thesis research on applying BID, discusses the Problem Driven vs. Solution Driven design process illustrated in Figure 14. The premise of this approach to problem-solving places priority on the problem versus the solution, i.e., the journey versus the destination. According to Chambers, the education system is the prime instrument for the delivery and honing of advanced sustainable design skills to students, and prepare them to become eco-leaders.

Problem Driven (Helms, Vattam, Goel, Yen, & Weissburg, 2008, p. 3)	Solution Driven (Helms, Vattam, Goel, Yen, & Weissburg, 2008, pp. 6-7)
Step 1: Define the Problem	Step 1: Identify Biological Solution
Step 2: Redefine the Problem	Step 2: Define Biological Solution
Step 3: Search for Biological Solution	Step 3: Extract Main Principles
Step 4: Define Biological Solution	Step 4: Redefine the Solution
Step 5: Extract Main Principles	Step 5: Identify Problems
Step 6: Apply Principles	Step 6: Define the Problem
	Step 7: Apply Principles

Figure 14: Comparison of problem-driven versus BID solution-driven approaches
(Chambers, 2011. Used with permission.)

Chamber's chart (Figure 14) illustrates the differing steps involved when practicing a problem-driven versus solution-driven approach. The solution-driven (or process-driven) approach is the one more utilized more by science-based disciplines, and therefore most applicable for BID. The course at the Georgia Institute of Technology, referenced by Chambers' (2011) study and chart Figure 14, is described in greater detail in the precedent study (Chapter 4, Section 3).

Naboni (2013) believes that there has been a shift from pre-2010 to post-2010 ecological mechanisms regarding BID. The educational trends, according to Naboni, have transitioned from high-to low-tech, and in his research, discusses the need for qualitative discovery beyond rating systems. A multidisciplinary matrix based on the LBC utilizes a 'toolkit' that includes a sketchbook, storytelling, and, students learn to connect with nature on a deeper level in Naboni's 2-week course. The study concluded the three key tools to be the principle's matrix, the design process map, and the sections, which the students used to analyse the sustainability of a large group of buildings over a ten-year span. Naboni believes that this toolkit was instrumental in

establishing architectural precedents that involved measuring a building's performance in the environment, valuable for future studies.

According to Sullivan (2011), interdisciplinary charrettes focussed on an actual design problem is an effective way to integrate biology into a project challenge. A full day immersion experience can result in a bonding experience between disciplines that perhaps had not pre-existed. Contributing to this methodology, McNamara (2012) believes collaborating with industry and community, such as with competitions, may add value and impetuous. Bio-design competitions and/or challenges provide students with active learning goals and opportunities to learn from other learner experiences (Niewiarowski & Paige, 2011). Design challenges and competitions are offering extraordinary opportunities to partner and practice with their ever-expanding BID toolkits

3.3 Delivering ID Education

According to Benyus (as cited in Kellert et al. [eds.], 2008) "a new breed of architect believes it's time to go back to school" to fully absorb and apply the new BID strategies (p.28). As desirable as an IDP may be to practitioners, Fry (2009) acknowledges that the firms 'redirecting' their business cultures to contribute to sustainability need to invest time in educating their staff, and there are practical limits to that effort. Clearly, the introduction of new topics must begin with the educators (Benyus, 1997; Fry, 2007; Orr, 1992). However, it was not until the 1970's with the support of the United Nations, that the importance of environmental education entered mainstream thinking (Dale & Newman, 2005). Institutions have been slow to integrate environment design as a requirement across faculties according to Fry (2009). *Ecological Literacy: Education and the Transition to a Postmodern World* (Orr, 1992)

supports the ‘knowledge = power’ approach to environmental sustainability. In this book, Orr discusses the theory that educators are poised to deliver a deeper ecological pedagogy and what those delivery methods should be. Orr states that “constructive postmodern thought provides support of ecology” (p.ix) and believes that “good thinking is inseparable from the breath and friction between an alert mind with well-conceived experience” (p.xii). Orr’s theories in ecological education form the foundation of this research in advancements to sustainable education.

3.3.1 Program Accreditation

As part of integrating BID into ID curricula, it is helpful to understand the accreditation of ID programs. CIDA is the organization that sets out professional standards, responsibilities, and evaluation tactics for post-secondary ID education. CIDA states that, “A sound curriculum for professional ID education must provide a balance between the broad cultural aspects of education” blended with profession-specific pedagogy (p. II-1). The criteria for accreditation clearly supports sustainable design strategies and delivery models encourage evidence based design (EBD) development. In CIDA’s role of outreach facilitation and in collaboration with four design association stakeholders, commissioned a report on the state of the practice and appropriate educational targets for the future (CIDA, 2014). In consideration of the multitude of recommendations reported in the Interior Design Profession’s BOK report of 2010, biomimicry may be a strategy that could bridge the knowledge-gap identified in the report, and facilitate the profession’s sustainable design evolution.

CIDA has become a valuable mechanism for theory to practice conversations, and has acknowledged that the ID profession is at a crossroads. ‘Future Vision’, held in

November 2014, was a CIDA facilitated forum where ID educators, professionals, and design-related stakeholders met to discuss what the profession and its direction (Coleman, 2015). According the Coleman's (2015) account of this meeting focused on ID education, the participants acknowledged change is overdue. Coleman states,

> "What comes with this changing definition is an increased emphasis on an improved value system for the design industry – a definition that encourages designers to move beyond problem-solving and order taking to an expanded role that looks to create unique, problem-specific solutions as a basis for design. This redefinition includes responsibility to today's and tomorrow's ID students by equipping them with new and more diverse skills sets; updating more relevant design methods and processes; and providing a language of leadership, purpose, and motivation for the challenges and opportunities that lie ahead." (p.x)

Coleman (2015) cited five key shifts articulated during this discourse visualizing 21st century ID education. These new values involve shifts toward:

- encouraging students to have high, uncompromising expectations of themselves and their design commitment
- preparing students with an evidence-based acumen, and the social-scientific research in their body of knowledge for a knowing discourse when defending their design decisions
- expanding the design student's awareness of place, and how collaborations with other disciplines will contribute to design performance and heighten the stakeholder experience

- design students taking a leadership role in breaking new ground and researching unexpected alternatives in pursuit of advancing the health and well-being of their clients, society, and the environment
- student learning that involves a worldview informed by a sensitively to diversity, morality, environmental stewardship, and design responses that portray a positive social conscience

Using a strategy of sequenced integration educators can make incremental bio-inspired shifts attuned with the future vision of ID education articulated in the think tank session. This discussion model, as defined by the Merriam-Webster Dictionary (2015), is a group organized for discussions involving research and the development of topics. Think tanks act as an effective multidisciplinary tool to exchange various viewpoints at one time.

The multi-layered structure of biomimicry provides educators with a systematic process to weave into ID curricula. CIDA's Professional Standards Overview contains several sections that include sustainable design objectives. Utilizing the BOK research findings, CIDA has spelled out specific criteria to guide ID education needs to evolve to meet its profession-based objectives. The sections that pertain to advancing sustainable design strategies are:

Section II. Interior Design: Critical Thinking, Professional Values, and Processes

- Global Perspective for Design
- Human-centered Design
- Design Process
- Collaboration

- Communication
- Professionalism and Business Practice
- Space and Form
- Global Perspective for Design
- Regulations and (Sustainability) Guidelines
- Expectations – multidisciplinary collaboration and interaction with multiple disciplines
- Standard 14 – awareness of sustainability guidelines

Section III. Interior Design: Core Design and Technical Knowledge (p. ll-6)

- Finish Materials
- Environmental Systems
- Interior Construction

Biomimicry encompasses the principles, processes, and practices that has the ability to respond to these accreditation guidelines. Greenberg (2012) states in his paper *Teaching Materials Through the Frame of Sustainability* that "[w]hen the student learns where materials come from and the resources that are used to deploy them, a door is opened to the broader implications of their designs beyond the walls of the interior" (p.1). The profession of 'interior' design, in its evolution, infers that designers work within physical limitations but with the expanding sustainable design demand and expertise, expanded opportunities will evolve and environmental design may be the more accurate term going forward (Brooker & Stone, 2010).

3.3.2 Methods and models

Some of the questions that need consideration when integrating biomimicry in ID curricula are: how should BID be delivered, to what extent, and to what level of students? CIDA (2014) outlines the assessment criteria for both standard and alternative methods for course delivery (p. II-4) to support both traditional and progressive access to design education. The accreditation guidelines encourage all programs to provide course modules for bricks-and-mortar, online, and self-study learners. Many of the program requirements pertain to all of the delivery models, and the performance criteria defined under the key categories of Student Learning Expectations and Program Expectations. Program administrators must submit their institution's intent on how they propose to meet these criteria and measure the outcomes for evaluation in order to achieve CIDA accreditation.

The question of when to engage in biomimic practices has more than one answer based on whom you ask. Kellert et al., (2008) believe this exchange of ideas needs to occur at the institutional level. Angne's 2012 study suggested that 60% of the educator respondents were teaching biomimicry at the undergraduate level. Benyus believes this interaction needs to happen in kindergarten if not earlier (Benyus, CaGBC Conference, 2014). The Biomimicry Institute provides curricula and teaching tools for educators stating at the K-12 levels, firm in their conviction that the earlier learners are introduced ecological responsibility the stronger the human-nature connection will be.

According to Kwon (2007), "Through design curriculum development, educators develop a context of design learning that supports the acquisition of design knowledge and has the potential to connect students into a larger network with the design

communities. Therefore, the core challenge of design education is how to develop curricular contexts and learning systems that extend themselves meaningfully into the personal and social life of everyone involved in the process; and to take it to a more flexible and sustainable level for the students' future competiveness" (cited by Frasier-Scott, 2012, p.18). How does the transformation between a sustainable design methodology and a worldview that participates with ecology as a basis our design decisions occur and evolve?

In Alawad's (2014) survey of ID students at the King Abdulaziz University, answers to the question of when to introduce BID in post-secondary education emerged. Firstly, when students were asked how early BID should be introduced into the curriculum 87% agreed that it would be a very valuable concept in year one. Next, Alawad's research highlighted that one lecture was not enough time to communicate the full scope of biomimicry so that the students could utilize the concepts to the fullest. The students also responded that they would prefer that this topic should be a core module in the curriculum versus taught in only once course. The students believed that biomimicry would inspire their creativity and encourage them to contemplate the environmental impact in their design decision-making. Alawad concluded that students were enthusiastic about biomimicry and believed it could translate into their design careers. Students are looking for ways to increase their competitive edge in the job market.

3.3.3 Creativity Generation

In my ID management experience, employers are looking for creative problem-solvers, as well as designers that understand the importance of benchmarks, outcomes,

and the value of evidence based design. Huber, Leigh and Tremblay's paper Creativity Processes of Students in the Design Studio (2012), describes a study conducted to understand the creative processes of thirty-six senior students during a design project. The student project involved the design of a scaled model of a chair. The students were required to respond to questions asked during the design process in their journals. Following the journal collection, the entries were analysed. Using domain relevant experience, creativity relevant skills, and motivation based on Araa-bile's (1996) framework of Computational Model of Creativity (cited in Huber et al., 2012), the researchers concluded that the key proficiencies that defined the students' levels of creativity were assessed based on these categories:

- Problem Seeking: used repeatability as a thought starter (drew on previous project problem-solving methodology)
- Analysis: demonstrated cognitive activities including utilization of theory, consideration of human factors, the ability to drill down (to create a set of core values)
- Generation: were uninhibited in their idea generation and formulated multiple design solutions (open to all possibilities)
- Ability to utilize and synthesize multiple or diverse analysis techniques to solve one problem (looking at ideas from various perspectives)

The 'high creativity' group, defined in the study, averaged more words and a deeper thoughtfulness as observed in their reflective journaling, required to complete the experience. Although not specifically addressed in this study, the studio format likely contributed to the collaborative environment and idea generation, more so than other

more structured learner settings and teaching vehicles. A discussion of the characteristics and outcomes of studio-based learning occurs later in this chapter.

The outcomes noted in the Huber et al., 2012 study, are an indication of how creativity may be affected through the makeup of various learner styles, and may be relevant to predicting the success of a project team utilizing IDP. Gale, Martin & Duffy (2012) stress that complex questions require complex answers, and acknowledge that: practitioners depend on interdisciplinary collaboration skillsets to apply sustainable design (p.1), and that well-honed skillsets such as critical thinking, teamwork, and communication skills are imperative to meet this challenge.

3.3.4 The Classroom as Teacher

"Rethinking the studio culture plays in the development of students' sensibilities about design and the environment" claims McDonough (2004, p.79). The C2C paradigm shift requires a new educational framework, according to McDonough, however research in this area over the last ten years is demonstrating progress. In my review of literature, studio-based learning appears as the most utilized delivery model for teaching SD; however, it is both teaching methodology and a place. But where is the best place to teach biomimicry? Perhaps a treehouse, a forest, a zoo or all of the above? This research endeavours to vet the teaching and learning strategies that are most effective for integrating biomimicry into ID curricula.

Studio-based learning in architecture and the arts originated in the 1800s, modeled after the active-based learning methodology from the Ecole des Beaux Arts in Paris. According to Lackney (1990), systems based on a "design problem" began with a sketch problem, was monitored by teachers, ended in a charrette, and had projects

judged by jury of professionals and guest architects. The Bauhaus School modified the studio-based teaching strategy to become more practical in nature, involving more hands on assignments and projects that involved actual “buildings under construction” (para.7). In 1963, the Bauhaus school’s director, Walter Gropius, became the head of Harvard University, utilizing the studio-based learning strategy to develop an interdisciplinary studio model integrating architecture, landscape architecture, and urban planning. Lackney (1999) believes that the design studio is the nucleus of the architectural and ID curriculum.

Natural immersion, according to Atchley et al. (2012) and others, is a simple and effective strategy in communicating biomimicry concepts to students. Spending time outdoors is essential to understanding ecology and is an inspirational tool in educating students about nature’s genius in situ (Benyus, 1997). Creativity in the Wild: Improving Creative Reasoning through Immersion in Natural Settings by Atchely, Strayner and Atchely (2012) presents their study findings whereby, once unplugged from the mechanized world, the control group illustrated a significant increase in creative problem-solving abilities. Their study deduces that nature has the ability to improve cognition, amongst various other benefits (Atchely et al., 2012). “After an interaction with natural environments, one is able to perform better on tasks that depend on directed-attention abilities” in part due to the restorative benefits of ones’ experiences in nature claims Berman, Jonides and Kaplan (2008, p.1207). The importance of associative elements in the creative process is also discussed in a study by Mednick (1962) stating “It should be clear that an individual without the requisite elements in his response repertoire will not be able to combine them so as to arrive at a creative

solution" (p.222). Studio-based learning is a phenomenological experience and is a much about the environment as it is the knowledge building (Poldma, n.d.). Experiences in natural settings have cognitive and associative benefits pertaining to the creative process that could not occur otherwise, according to these studies, and the outdoors is biomimicry's classroom.

Outdoors or indoors, the studio-based learning model allows time for students to take pause and reflect on their own work and progress. Where better to do this than in a forest, by a river, or in a field when learning nature's lessons? Clark (2006) cites Schön's (1987) theory regarding educating the reflective practitioner and the role reflection plays in the transition from student to practitioner. Schön states "Competent practitioners must not only solve technical problems by selecting the means appropriate to clear and self-consistent ends; they must also reconcile, integrate, or choose among conflicting appreciations of a situation so as to construct a coherent problem worth solving" (cited by Clark, 2006, p.584). Simply put "what we do as interior designers and how we do it" (Poldma, n.d., p.107). There is no one answer to the question of 'place' for biomimicry to be taught, however this research attempts to understand the parameters that will enable Canadian ID educators to engage in the discussion.

3.3.5 Curricula Considerations

Although traditional biomimetic collaboration paired engineering and biology, the Bauhaus School of Design in Germany (1919-1933), blended the arts for better-rounded teaming (Findeli, 2001). It is one of the earlier documented examples that utilized BID in problem-solving with combined expertise. Since then, one of the best-documented examples in the development of BID curricula is out of the Georgia Institute of

Technology, in the U.S. This institution offered an experimental course in 2005 that intertwines science, technology, engineering, and math (STEM) undergraduate and graduate students. The course development was accessed and student outcomes observed until 2009, as chronicled by Yen, Weissburg, Helms & Goel (2012). Out of the many outcomes noted, one key observation related to the ratio of learners from various disciplines (see Figure 19). The researchers recognized that expanding the discipline-base beyond STEM learners, and including other students from other faculties, would enrich the design-thinking process and balance idea generation for a less restrained outcome then would have resulted with only engineering students.

A more contemporary course pilot was presented in Angne's (2012) research study where biomimicry was introduced to ID students. Angne's study explored the application of the Design Spiral, created by Carl Hastrich at OCADU and owned by Biomimicry 3.8, as a key tool in the design of her course. Angne looked to nature for inspiration when developing the 11-week ID course that integrated biomimicry methodology into the studio project criteria (discussed in the precedent study in Chapter 4, Section 5). The course trial resulted in a realization that 11-weeks was an insufficient timeframe for the students to research, digest and apply the biomimicry strategies. The cyclical structure the course design required a longer semester. Angne (2012) discovered through her own course assessment that the curriculum would need some adjustments. Due to the complexities of biomimicry methodologies, sequencing its integration into curricula is paramount (Benyus, 2011). Angne's research discovered that unfamiliar and complex issues that biomimicry brings to ID pedagogy, requires reflective time for the educator and student alike.

Other popular techniques for teaching BID topics researched uncovered: in situ experiences; tracking projects through their life cycles, including the deconstruction process (through text and photo-documentation); mock-ups and modeling; charrettes and design challenges. Based on the importance of how to effectively teach SD as opposed to "the creation of course content and materials" (Wallack & Webb, 2007, p.78), my study explores the educator-focused fundamentals of what is working and what is needed to teach biomimicry in the post-secondary ID education.

3.3.6 Deep Learning

In 1976, Marton & Saljo recognized that in order for students to utilize higher-level cognitive skills for the processing of complex issues, particularly ones requiring interdisciplinary problem-solving, deep learning was required (Wallack and Webb, 2007). Biomimicry is a methodology that may be easily grasped but is not necessarily one this is easily applied. Wallack and Webb, in their paper presented at the 2007 IDEC Conference, state that from a research study (Warburton, 2003) focusing on sustainability in higher education, deep learning was critical to educating learners in the interdependence of systems and application complexities. Warburton states, "Deep learning strategies cannot be externally imposed and must be interest-led" (2003, p.54). This is of particular concern especially when crossing "the divide between science and the humanities" (Warburton, 2003, p.54), based on the varying learning styles. As well, Warburton's study concludes that the students' project documentation process and reflective journals were essential to facilitating deep learning.

Schön (1987), author of the *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in Professions*, has studied the balance between the

"covert things" and "the doing" the concepts of design experience that cannot be learned otherwise (p.81). Based on his theory of "action research" in an article Schön authored in 1995 on new scholarship, he believes that reflection must be part of the design process and conducted as part of it. Biomimicry employs a continuous documentation process and requires the design team to undergo contemplation and assessment on an ongoing level that is instrumental in the problem-driven versus solution-driven approach. The analytical skillsets and deeper investigation of underlying ecological concepts exhibited by the students in the Warburton (2003) study was an indicator of a more profound appreciation of nature and their participation in its preservation.

Another foundation of the deep learning theory is motivation. Wallack and Webb (2007) state that, "Critical to this discussion is the concept of [a motivational] system where each element impacts every other element" (p78). This mirrors Warburton's (2003) conclusion regarding learning being interest-led, and Schön's (1987) theory on action-learning to engage learners. McDonough (2004) believes that in order for students to evolve into C2C designers they must embrace motivation, and become empowered by it. Angne (2012) suggests that that by finding ways for students to "fall in love with nature" could motivate them to participate more as activists and less as by-standers. Alawad (2014), in his research investigating triggers to enhance student creativity, observed, "Mother Nature's forms and patterns may inspire and motivate students of ID in their own creations and conceptual designs" (p140). This research attempts to investigate additional motivational models to better understand how best to engage designers in sustainable design curricula. Simply put "the more people learn

from nature's mentors, the more they'll want to protect them" explains Benyus (cited by Angne, 2011).

O'Keefe (2014) discusses the correlation between motivation and successful learner outcomes by examining Csikszentmihalyi's theory of 'flow'. O'Keefe researched various psychologists' studies on learner success strategies and found that there was a consensus that when students were 'in the zone' they stayed engaged on the exercise or topic longer and on a deeper level. For the students studied, being 'in the zone', meant that they looked for personal relationships and relevancy to their lives and futures, particularly when the topic (like science) was introduced to a typically non-science-based discipline. Again, journaling was the methodology that supported these conclusions, aiding educators in better monitoring and evaluating the outcomes of the O'Keefe's research.

3.4 Challenges to Teaching Biomimicry

Of the various common threads in the literature, two dominant challenges to utilizing biomimicry methodology were raised: language and time. When crossing disciplines, the exchange of problem-solving approaches and terminology was essential for positive team dynamics. This, among other processes in utilizing BID strategies takes time: time to comprehend biology-based concepts, time to apply them, iteration time, reflection time, assessment time, and time to shift from a mechanized to an ecology worldview.

3.4.1 BID Nomenclature

As Helms et al. (2009) point out in their research, the various bio-design disciplines speak different languages, inherent in their approach to problem-solving. For

example, biologists explore the pre-existing processes in nature whereas engineers formulate new solutions based on man-made elements (Vincent, 2009, as cited by Niewiarowski & Paige, 2011). This means that engineers are largely solution-driven problem solvers whereas biologists are problem-driven problem solvers. The interdisciplinary requirements of biomimicry predispose the implementation of the process to various cognitive and communication challenges. IDP team members may learn and communicate in domain-specific ways, however, must be open to adopting a common (or natural) language to facilitate research, and avoid bias and miscommunication between the disciplines in BID research and collaboration (Shu, 2010; Warburton, 2003).

The research presented at the ASME 2001 Design Engineering Technical Conference, *Towards Biomimetic Design Concept Generation* (Vakili & Shu, 2001) concludes that a common language increases the chances of finding appropriate correlations between nature and design problem-solving. Vakilli and Shu (2001) believe that in addition to establishing methodologies to conjoin the disciplines, diagrams assist in identifying and explaining complex biological functions when pairing biology with design applications (Figure 15). Word libraries that translate biological processes into a common language bridge multidisciplinary gaps (Shu et al., 2007).

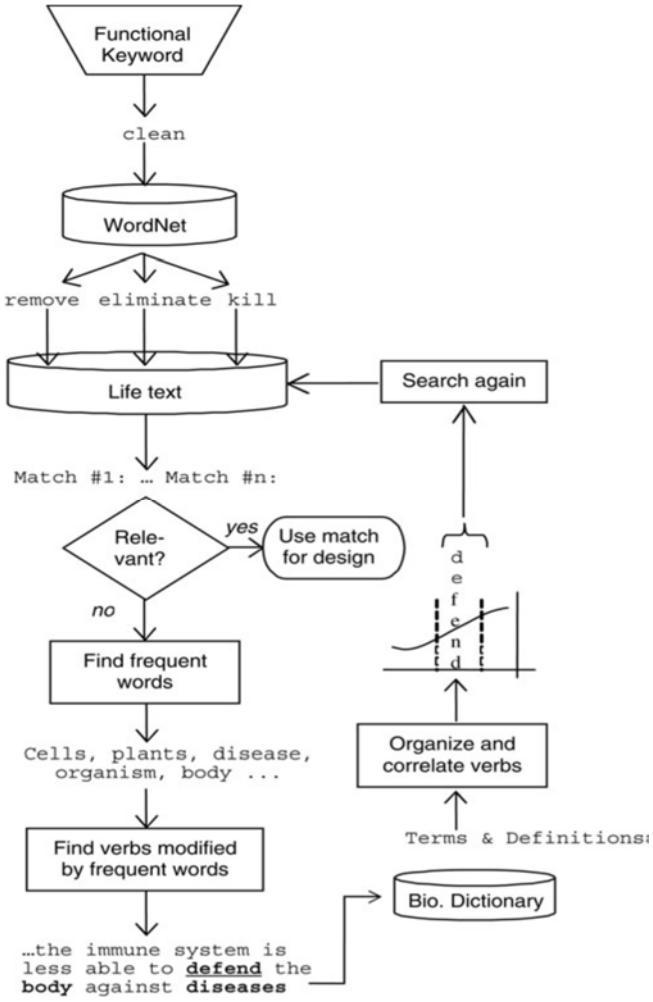


Figure 15: A flow chart of the method bridging the keyword 'clean' to 'defend'.
(Fig.1. Adapted from "Bridging cross-domain terminology for biomimetic design", by I. Chiu and L. Shu. Proc. ASME 2005 Int. Design Engineering Technical Conf. Computers and Information in Engineering Conf., Paper No. DETC2005/DTM-84908, Long Beach, CA. September 24-28, 2005. Copyright ASME 2005. Used with permission.) (Shu, 2010)

Sarkar and Chakrabarti, in their 2008 research, determined that visual representations of biological functions were a more effective language for multidisciplinary problem-solving (cited by Helms et al., 2009), hence the popularity of AskNature for biomimics. AskNature, as an openly accessible database of BID resources and appropriate definitions (Santulli & Langella, 2010), is an invaluable resource for interior designers. Interior designers depend heavily on ideation for

problem-solving and communicating their ideas throughout the design process. A visual tool that crosses disciplines provides a common language for all IDP team members, and supplies them with a broader supply-chain of BID resources than they might have had access to otherwise (Niewiarowski & Paige, 2011).

In the webinar document Systems Tools for Interdisciplinary Teamwork in Biomimicry, McNamara (2012) discusses the research he has conducted with his students at the Minneapolis College of Art and Design (MCAD). Various communication and systems thinking methodologies have been explored regarding "biologizing the design question" on project assignments involving BID (p. 52). McNamara acknowledges that some methodologies integrate biology into the design process more than others, however he stresses the importance of utilizing communication tools to unify various perspectives and skill sets when connecting the disciplines.

Enabling biomimics to not only effectively communicate across disciplines but also with their clients and other stakeholders is another compelling argument to support the development of a common language (Naboni, 2013). Once this BID language is established, Naboni believes it will replace an "ambiguous nomenclature" that overuses terms such as "green" and "sustainable" that diminishes the real value of ecological research and advancements in the built environment (p.4). Fry (2009), based on experience as a practitioner, supports this theory in *Design Futuring* stating that "the manner in which design is mobilized in language to signify intentional action and a comprehension by the population at large of what design practices can or cannot do is another great divide" (p.45). A common language provides for clear and democratic communication in the evolution towards an ecological worldview.

3.4.2 Time: Acquiring and Applying BID Knowledge

The most compelling and widely relatable concern regarding the integration of BID, centered on 'time' in many contexts. Within the literature, educators and practitioners alike discuss the effect that time has on the learning curve, time management and incubation time, and offer suggestions to adapt to those challenges. According to Fry (2009), Aristotle defined time as a plural concept and defines many measurements and relativity. For example, humans measure time by age and in relationship to one's lifespan in the universe.

Savitsky (2006) refers the time learners need to grasp concepts as "cook-time", and integrating BID tools into a single semester multidisciplinary course needed to be methodically introduced, one tool per week (p.16). His study observed that when introducing students to complex topics, repeating the concepts through the same lens improved their ability to comprehend them. One of Angne's 2012 research conclusions mirrors this observation, noting that the time required to introduce biological principles in a repetitive 3 to 4-week cycle over the 11-week semester (Figure 21). In monitoring the course outcome, she assessed that a 16-week semester would be to allow students more time for design iteration. Biomimicry requires a shift in how problems are solved, and the transition from problem-driven solution-driven challenges the time available in a single semester (Helms et al., 2009; Santulli, 2010). Introducing complex new topics into education and practice, involves a longer learning curve that often is not available in a single semester. Verbeek (2011), in her research in industrial design manufacturing, found that bio-design might extend project timelines, which is a concern for the design

disciplines in project delivery. Learning, exploring, and translating BID strategies may impose a timeline concern for teachers and practitioners.

Repeatability (the time to practice and develop a concept so it can be repeated), was a common term expressed when integrating BID strategies (Helms et al., 2009; Savitsky, 2003; Verbeek, 2011). Helms et al. (2009) referred to the process of practicing the steps involved in BID as "refinement loops" (p.610). Although not specifically stated in Helms et al. 2009 study conclusion, but evident in Angne's (2012) research, was that students would benefit from more time for repetition and reflection. The specific outcomes in Helms et al.'s research relate to the students' lower than expected utilization of solution-driven principles and the successfully balance the application strategies.

McDonough and Braungart (2002) also discuss the need for designers to build in time for experimentation, and time to prepare to innovate further, based on their project experiences integrating C2C principles with their long-term client the Ford Motor Company. Designers need to understand and prepare for the learning curve of biology inspired and regenerative design (McDonough & Braungart, 2002). Practitioners advise others to make time to manage change, and the effects it has on the changing roles and opportunities of the designers (Fry, 2009; McDonough & Braungart, 2002; Sorrento, 2012; Verbeek, 2011). According to McDonough and Braungart, transitioning designers must "Recognize that change is difficult, messy, and takes extra materials and time" (p.184).

Many of the researchers noted time for reflection as imperative for the successful integration and utilization of BID strategies (Findeli, 2001; Schön, 1987; Sullivan, 2011;

Wallack & Webb, 2007). Not only is reflection instrumental to the learning process but as important for assessing the outcomes, and next steps. Moxon (2012) observes that rigour and critical thinking skills need time to develop, highlighting the challenges that interior designers experience with shorter term projects as compared to the longevity of architectural projects (Moxon, 2012). Smaller-scale projects may pressure interior designers 'just-in-time design' solutions to satisfy a fast-moving client culture seeking instant answers (Moxon, 2012; Sullivan, 2011).

My clients often opted for a 'design-build' project methodology as compared to a traditional project delivery process where each phase is sequential. By utilizing a design-build process the project phases overlapped, allowing more time to explore cost and design options, resulting in a more collaborative IDP team and client experience. Educators too require time for reflection, and Schön (1995) believes that if institutions are to evolve then they must facilitate reflective practices. He states that "Higher education will have to learn organizationally to open up so as to foster new forms of reflective action research" but acknowledges that due to the nature of the respective institution may become bogged down in traditional values and administration (Schön, 1995, p.34).

BID inherently requires a shift of mindset, when involving nature to answer technological questions according to Cas Smith, Project Manager at Terrapin Bright Green in their webinar Tapping into Nature: Bioinspired Innovation (2015). Smith claims that the BID product development process can take years of iterations before a design solution is ready for the market. My literature review uncovered the effect that time has on a shift of worldview, and how essential reflective time is in the evolution towards

ecological enlightenment (Orr, 1992). 'Time' was reported by some research studies and educators to be a powerful denominator in the adoption of world-changing strategies like biomimicry.

3.5 Observations

The literature reviewed revealed the origins, curricula development, program criteria, and educator-learner challenges of delivering BID education to interior designers. It is clear that SD strategies will not advance without the inclusion of multiple disciplines, a common language, and the skill sets to facilitate it; hence, some of the complexities of practicing biomimicry. "If design is to live up to its promise it must create new, enduring curricula for design education that merges science and technology, art and business, and indeed, all of the knowledge of the university" (Norman & Klemmer, 2014, p.2). This is a meritorious target but how achievable is it?

This literature review has uncovered both hi-tech to low-tech strategies for applying biomimicry, from online database AskNature, to immersion in nature. Various disciplines relate to the bio-design methodologies differently, hence the need for more than one strategy to understanding and teaching biology-based subjects. A shared and searchable multidisciplinary database, like AskNature, seems to be the fundamental tool for learning about biology-design relationships and applying them effectively. The importance to tracking theory-to-practice data is essential to the development of BID utilization and outcomes (Remington-Doucette, Connell, Armstrong & Musgrove, 2013). "Metrics for evaluating the output, in terms of creativity, communication, cross-domain transfer, and design skills are needed," states Bar-Cohen (ed. Y Bar-Cohen, 2012, p.355). BID tools and methodologies assist various expectation and performance

criteria. Journaling and charrettes contribute to student comprehension and assessment guidelines. BID student challenges/competitions assist in addressing process, application and collaboration skillsets, and assist in satisfying the various program delivery expectations. Biomimicry research and curricula models are deliverable in a multitude of learner environments and to a diversity of learners.

Of the various strategies and tools researched, there is a consensus that the BID vehicles for teaching and learning need to:

- focus more on the process and less on the product
- monitor the process and track the outcomes
- facilitate the development of interdisciplinary relationships that reward creative thinking and team equity
- offers communication opportunities and common language platforms
- encourage ID students to develop an ecological conscience and expose them to future career streams when integrating biomimicry into their projects

The acquisition of new knowledge and evidence-based design precedents are only two of the many benefits when weaving biomimicry into ID curricula and practice. The swell of U.S. research greatly influenced the design of the survey studies. The educator feedback from the surveys, along with the precedent studies, will endeavour to situate the state of biomimicry in Canadian ID education today and for the future. The correlation between the research methods that follow informs the conceptual framework development for Canadian ID educators to integrate biomimicry into their programs.

4.0 Research Findings and Discussions

This chapter presents the research findings and analysis of the data collected from biology inspired design (BID) education strategies and experiences through questionnaires, semi-structured interviews, and a precedent study of seven BID and biomimicry courses. Comparisons between the Canadian and U.S. respondents are presented and analysed, highlighting: educator experiences, interdisciplinary outcomes, BID and biomimicry integration, methodologies, tools and delivery models, as well as student outcomes and educator feedback. Appendix D contains the detailed questionnaire and responses. The semi-structured interviews with educators were conducted with those participants who volunteered at the conclusion of the questionnaire survey. Their responses were analysed according to various themes that evolved during the discussions, and are presented later in this chapter.

The precedent study consists of an examination of a total of seven undergraduate BID and biomimicry courses from U.S. and Canadian institutions. To understand the makeup of BID courses, they were dissected, summarized, and compared for similarities and differences. The findings of the precedent study analysis, presented later in this chapter, form the basis for the proposed strategies to integrate biomimicry into ID programs for Canadian educators.

4.1 Questionnaire Survey

A letter of introduction to the thesis study was emailed to 35 U.S. and 35 Canadian post-secondary educators teaching ID and design-related undergraduate courses linking them to an online questionnaire. Although the questionnaires were the same, participant responses were collected separately based on which country their

program originated (so that the responses could be compared by country). The US response rate was 23% (8/35 respondents) and 46% (16/35 respondents) for Canada. Angne's U.S. response rate was 10% (50/500), although the number of respondents were much larger in total than my study. Whenever possible, I compared the results of my questionnaire survey to Angne's US survey findings (2010) to learn if there was evidence that biomimicry integration had advanced further into ID programs over the four-year period between the surveys. For the Canadian data, the goal was to confirm the current extent of biomimicry education, to reveal the strategies they employed and challenges they experienced.

4.1.1 The Magnitude of BID Education

The questionnaire response rates were strong considering the number of participants invited to be surveyed, and twice as many responses were received from Canadian educators (n=16) than from U.S. educators (n=8). According to the responses from Question 2 (Q2), 100% (8/8) of the U.S. participants teach SD, whereas in Canada 67% (10/16) of the ID educators teach SD. According to responses from Q3, the U.S. respondents teach LEED as their primary SD strategy, whereas contrary to indications from my literature review research, Canadian educators that indicated that they teach biomimicry more often than LEED. U.S. participants responded that 5/6 educators have been teaching BID strategies for between 1 and 5 years or more, 9/14 Canadian respondents do as well (Q6). The number of Canadian educators with this level of experience teaching BID contrasted with my research to date.

Question 5 lists a number of reasons why Canadian educators do not teach BID strategies. The multiple-choice option that Canadian educators responded to most was

'that their curricula was full and could not accommodate additional content' (Q5). Only 1/10 Canadian participants responded that their educators were not aware of the topic. The fact that so many Canadian educator respondents claim to have been teaching BID for that many years was unexpected considering how few online program descriptions indicate BID as part of their SD courses. It is possible that those Canadian educator respondents were the participants mined from the BEN database, however, as this was an anonymous questionnaire it is impossible to confirm.

4.1.2 Collaboration Skillsets

Strategies to support interdisciplinary and multidisciplinary collaboration are vital to the success of BID education therefore, the survey included questions to investigate collaboration methodologies when crossing disciplines. There were no clear answers from respondents when determining proven methods for blending discipline-specific students other than by encouraging their students to take courses in other programs. Six out of nine Canadian educators open their courses to other disciplines, however one respondent answered that 'their curriculum is full to involve interdisciplinary strategies', and another responded that 'they do not have the educator resources to teach it' (Q10). One responded from both countries responded to Question 10 that they 'do not teach interdisciplinary strategies as it's too complex to administer'.

The study revealed that 4/5 U.S. respondents believe that teaching a 'common language' is one strategy they employ when crossing disciplines (Q10). The literature review confirmed that a common language is an essential biomimicry communication tool, and U.S. respondents confirmed that understanding terminology and cooperation between disciplines were the primary student challenges on interdisciplinary teams. For

example, according to Angne's research, one of the methodologies U.S. ID educators involves integrating their ID students in interdisciplinary labs with biologists. This blending of disciplines provided learners the opportunities to exchange their discipline-specific problem-solving strategies and vernaculars, to advance their collaboration skill sets (Angne, 2012).

Educators from both countries responded that they believed that understanding terminology to be the challenges students faced when learning interdisciplinary concepts (Q12). Moreover, while 4/9 of the Canadian respondents noted that they do not have interdisciplinary students in their program, both country's educators answered that letting go of design authorship, understanding other disciplines' problem-solving methodologies, respect and cooperation among the students were also challenges. One U.S. participant commented that 'negotiating shared values and language' was another interdisciplinary challenge. These interdisciplinary and multidisciplinary challenges transition directly into professional practice. Students graduating with IDP skill sets will be highly valued by employers in my experience employing and managing interior designers of every professional level.

When the survey participants were asked to elaborate on what disciplines from other departments that participated in their courses, 3/5 U.S. respondents noted that students from industrial design, graphic design, and environmental psychology students were known to have participated in their ID courses with the remainder being from architecture and science (Q11). Canadian ID educators (6/9) responded that the other non-ID students in their courses were primarily architectural, with students originating from business, engineering and/or science departments to a lesser degree. U.S.

educators (2/5) and 4/9 Canadian educators responded that science students are invited to participate in their courses (Q11). Educators from both countries added comments noting a wide variety of disciplines participating in their courses, and Canadians included music students as well as students from fish and wildlife programs. These non-design students are evidence of the broader multidisciplinary mix that BID methodologies employ, and exemplify the importance of strategies and tools that can engage this broader student make-up.

4.1.3 Integrating Biomimicry

This section discusses the participant responses when asked about their strategies for integrating biomimicry into their programs. These questions focusses on the extent to which and in what context biomimicry was taught, as well as the methodologies and delivery models for teaching it.

In Angne's 2011 survey of the U.S. design-related educators, 10% were unfamiliar with biomimicry, 30% responded that biomimicry was not taught in their programs, and 56% of the educators responded they taught biomimicry in their programs (Angne, 2012). In Question 13 of my 2014 survey, 3/5 (60%) U.S. participants responded that they are teaching biomimicry in at least one of their courses, and 2/5 are teaching it in 2-4 courses. In that the 5/8 U.S. respondents answered the question that equated to 62.5% overall, a 6.5% increase in biomimicry education between the two surveys, with aligns with my literature review conclusions. Had the questionnaire respondent quantity from the U.S. participants in my study been equivalent to Angne's study, that outcome could have been exponentially higher. Canadians (3/9) responded similarly however, 4/9 responded that they are teaching it in

2-4 courses, an overall response rate of 7/9 (78%) indicating that biomimicry has a much stronger than expected presence in Canadian design-related education.

U.S. and Canadian ID educators responded to Question 4 that they integrate SD primarily into Methods and Materials courses. When asked, 5/6 U.S. and 3/7 Canadian respondents were unaware of any other programs integrating biomimicry at their respective institutions (Q11). One U.S. educator commented that biomimicry was part of an Optimal Healing Environments course, and two Canadian educators responded that an environmental course and an engineering department had incorporated biomimicry (Q16).

The questionnaire results indicated that educators integrate biomimicry into their courses most effectively in various learning environments. In multiple choice Question 15, 4/6 U.S. educators selected the studio, whereas 6/7 Canadian educators integrate biomimicry into lectures, followed by lab (3/7), and then field study (1/7). Angne's 2010 survey found that 90% of U.S. educators responded that their teaching methodologies were lecture-based, 89% were studio-based, and 45% were in labs. Based on Question 21, educators responded that a majority of their programs are taught on-campus. Of the thirteen survey participants combined from both countries, only one Canadian educator respondent indicated that they taught an SD course online. My literature review and precedent study research shows that there are a growing number of online SD, BID and biomimicry courses offered in the U.S. at the graduate level.

Comparing my questionnaire results to Angne's, studio-based instruction surpassed Angne's findings as the most popular teaching methodology in the U.S. Coincidentally, the Canadian educators responded to the question of biomimicry

teaching methodologies in my questionnaire in the same order as the U.S. respondents did in Angne's 2010 questionnaire. This outcome may be representative of the path that integrating biomimicry has taken in U.S. education, or it could be professor-driven. Field study was the least used teaching strategy according to all of the respondents, although according to my literature review research, it is considered essential to enrich the student's understanding and application of biomimicry (Atchely et al., 2012).

According to both the U.S. (5/6) and Canadian (4/6) ID questionnaire participants, case studies are the most effective biomimicry teaching technique (Q17). For U.S. respondents the Biomimicry Taxonomy chart produced by the Biomimicry Institute (Appendix C) and the Design Spirals (Figure 21) are equally popular teaching tools (2/6 respectively) (Q17). Second to case studies, 3/6 Canadian respondents utilize the Biomimicry Taxonomy chart, followed by field study, Design Spirals, and charrettes. A U.S. respondent utilizes competitions as a teaching tool but the Canadian respondents do not according to this survey. This response was unexpected as student teams from two Canadian universities won global student design competitions utilizing biomimicry strategies in 2015. According to Precedent Study 6 and 7, Canadian students from OCAD students participate in competitions as part of their course work.

4.1.4 Student Outcomes

Although biomimicry is a relatively new concept for ID educators, survey responders provided valuable feedback for advancing biomimicry in their programs. The questionnaire surveyed how students respond to biomimicry, the resources they employ in biomimicry knowledge building, the student and educator challenges, and outcomes to inform course development.

When asked from where students seek out BID research the U.S. participants responded that the Internet is sourced equally to books and/or printed materials (Q8). Similar responses from 7/9 Canadian educators reported that students refer to the Internet, and 6/9 respondents noted books and/or printed materials are 'go to' resources by their students. Canadian educators also responded (4/9) that their students found practitioners as a resource. This response was unexpected, as the research uncovered few Canadian BID practitioners in Canada beyond Mau, HOK and RTRV. The educator comments did not reveal which practitioners the Canadian students are referring to, however, based on the Internet being a primary resource for these students it is probable that they are sourcing practitioners in this and other countries.

When ID educators were questioned (Q7) how well students were applying biomimicry strategies, 2/4 U.S. educators believe that 50-75% of students apply BID effectively, however only 3/9 Canadian educators had the same response. Educators from both countries responded similarly in that when offered SD options, students choose other strategies than BID. Respondents comment in Questions 18 and 23 believe that the students who engage with nature learn to value nature's lessons and ecology the broader context. Understanding how biology and design relate are the

primary challenges students express according to 4/5 U.S. educators (Q9). Locating BID expertise and resources is the primary student challenge applying BID claim 5/9 Canadian respondents. Comments from Canadian educators where telling, noting that conceptualization is a problem, and understanding the functional aspects of organisms. One respondent commented that students show interest in BID once they overcome the initial challenges. Question 18 also addresses the feedback from students when introduced to biomimicry. The majority of responses to this question were positive overall. Although a Canadian educator commented that some students find biomimicry "irrelevant", admit "it depends on the student". Feedback from U.S. respondents notes that students became excited about biomimicry once they understood it, and became more ecologically mindful.

4.1.5 Educator Reflections

According to 3/6 U.S. respondents, application strategies is one of the greater student challenges, although 3/6 Canadian respondents did not report any unique challenges (Q19). It is uncertain as to why this outcome is more of a challenge to the U.S. educators as compared to those in Canada. It could be that the teaching biomimicry has deeper roots for U.S. educators, and they may have encountered more challenges over a longer period. U.S. participants also responded with a wider variety of answers to Question 19, and one educator from each country responded that measuring student outcomes was a challenge when teaching biomimicry. Educators from both countries responded that biomimicry is applied equally well by undergraduate

and graduate students, and although the questionnaire was focussed on undergrad programs, the majority of students utilizing BID are at the graduate level.

Questions 23 and 24 of the survey focussed on lessons learned and the future of biomimicry education in their programs. Advice from the U.S. questionnaire respondents to other educators was: (a) that visual aids are essential, (b) converse with others who have done it, and (c) provide learning opportunities that allow the students to fall in love with nature. Canadian responses were enthusiastic commenting: (a) keep up to date, (b) just do it, (c) just get started and look for ways to get a conversation about nature started, and (d) get onto it quickly, as it is an expectation in 2014 and required by CIDA (Q23). When asked, in Question 24, if participants forecasted adding BID strategies into their design curricula all of the U.S. respondents indicated that they either are or will be within the year. Although 4/6 responses from Canadian educators responded similarly as the U.S., the reasons for not integrating BID or biomimicry that accumulated throughout the questionnaire were:

- integrating new topics was as a result of professional or personal interest and is professor-driven as opposed to program-driven (Q1 & Q5)
- biomimicry isn't a program subject target (Q5)
- BID is too advance for undergrads(Q5)
- curriculum is full and can't accommodate any more content (Q5)
- curriculum is challenging the students enough without adding biology (Q5)
- not thinking about it for a few years(Q24)
- busy trying to meet CIDA accreditation and practice act deadlines (Q24)

Meeting CIDA criteria is clearly a concern for Canadian ID educators. IDC states on their website that all baccalaureate degree granting programs must meet CIDA requirements by January 2017 in order to the association's minimum education requirements (IDC, 2015). The only exception to this is in Quebec ID programs, which have an extended timeline for CIDA.

4.1.6 Questionnaire Analysis and Observations

In contrast to the literature review and questionnaire, this survey tool provided fewer U.S. respondents and more Canadian respondents than expected. As well, considering the wide berth between the U.S. and Canadian CIDA accredited ID programs (172-U.S. versus 6-CAN), the 46% response rate from Canadian educators was encouraging. In addition to the survey questions, the participants added many enlightening comments: 45 comments from Canadian respondents and 19 from U.S. respondents. This demonstrated to me that Canadian educators were very engaged in the topic of biomimicry, and invested in the outcome of this research.

Teaching LEED as a SD tool for interior designers remains an important part of the curricula, however this questionnaire indicates that BID and biomimicry is integrating the Canadian design curricula. Canadian respondents who teach SD introduce biomimicry and C2C concepts when the curriculum permits. The educators believe that primary root of students' frustration with biomimicry concepts stems largely from their lack of comprehension, the deep thinking skill sets required to apply it, and/or a lack of appreciation for the value biology brings to the design process.

According to the ID educator respondents who include interdisciplinary tactics in their programs, teaching a 'common language', as discussed in Section 3.4.1 of the

literature review, is the first step to building teams with various disciplinarians. A common language is essential for students from different disciplines to communicate their ideas in a common forum. Multidisciplinary students need to be open-minded and considerate of each other discipline-specific vernacular and problem-solving methodologies, in order to negotiate a language that is democratic for all of the team members. Goel et al. (2015) conclude that, through their extensive case study research of student collaboration in interdisciplinary settings, digital study libraries (DSL) are valuable learning and teaching tools in BID courses. Digital libraries defining biological systems, such as AskNature, assist in developing a common platform for interactions across the disciplines. Collaboration skillsets are invaluable for students as the stakeholder circles expand beyond their discipline, institution, and into their careers.

Although a higher percentage of Canadian ID educators in this study open their courses to students from other disciplines, and encourage ID students to take courses offered by other disciplines, there is little evidence that it is happening. At least two survey respondents noted that a lack of integration between related disciplines is due to administrative complexities, a lack of educator resources, and simply the way that departments are structured. Orr (1992), an educator and author of *Ecological Literacy: Education and the Transition to a Postmodern World*, states that "Any adequate response to the emerging agenda of the twenty-first century will require great institutional flexibility, willingness to experiment, funding and patience" (p.147). As a faculty member, Orr claims, "Institutions of higher education are not well structured to encourage renaissance thinking; yet the logic of environmentalism requires no less" (p.147). It seems clear, that although integrating complex subjects like biomimicry into

existing programs institution-wide is ideal, Canadian ID educators believe it is more practical to develop a stand-alone course as a first step. Offering a biomimicry course, open to all disciplines, may be the best-case scenario if educator resources with biomimetic knowledge is limited, as opposed to waiting until several educators are ready to teach it in multiple courses.

Distance education courses may be another viable option for Canadian educators to introduce a new topic when there are limited educator resources with specialized expertise. Online courses, offer an independent learning environment to a broader student body with a minimum of educator resources. An online biomimicry course could satisfy additional curricula objectives, particularily when an ID program is struggling to meet CIDA standards, and their institution mandates the delivery of more online courses to their students. An online elective course in biomimicry could benefit a several programs in a variety of disciplines beyond ID, and build a cyber-network of student biomimics, as BEN has.

The survey analysis determined that tracking outcomes is a common challenge among educators. Although finding the time to assess student outcomes and course development seemed to be a teaching challenge, it was not an impediment to introducing biomimicry into courses for ID educators, according to my survey. Although one comment from a Canadian ID educator indicated that meeting accreditation and practice act deadlines was a priority for their institution, there was an unmistakable enthusiasm that biomimicry was a topic worth integrating. I found it curious when one Canadian educator responded that introducing biomimicry would assist in meeting CIDA criteria (Q23) whereas another in Question 24 believed that introducing a new topic (like

biomimicry) would detract from their program's CIDA objectives. Surprising, as well, is that the introduction of new topics is professor-driven as opposed to program-driven. Based on this, and the questionnaire analysis, I surmise that ID educators, once informed, could be the trigger to the advancement of biomimicry education in Canada.

Lastly, was the observation that number of respondents declined as the survey questions transitioned from SD to biomimicry education experiences. In both Angne's (2012) survey and this study saw an average reduction of U.S. responses by 30%. In my survey, Canadian educators exhibited a 45% reduction rate in responses about their biomimicry education experiences. The U.S. rate of response, identical to Angne's 2010 survey, indicates that the integration of biomimicry education at the undergraduate level is status quo, whereas there is an incline of biomimicry course at the graduate level. For Canadian respondents, I wonder if although they may be starting to integrate biomimicry it into their ID programs fewer have been teaching it long enough to reflect on it as compared to SD.

4.2 Semi-structured interview Survey

The semi-structured interviews provided an opportunity to speak with ID educators one-to-one about their experiences integrating biomimicry into their curricula. The interviews commenced with a discussion of survey questions that were unanswered, and/or required clarifying and then transitioned into a discussion of three or four open-ended questions. The focus of the interviews was specific to teaching

strategies and challenges, lessons learned, and insights relating to the integration of biomimicry into ID curricula.

From the questionnaire respondents, two interviews were conducted from both Canada and the U.S. The results, of which, are presented herein anonymously. The educators were diverse in their backgrounds, teaching experiences, and biomimicry knowledge. These variables provided the study with a cross-section of educator perspectives, as well as overlapping viewpoints for advancing biomimicry education.

4.2.1 Interview 1 – U.S. Participant

The first of the two U.S. interviewees is an ID educator who began weaving biomimicry into an 11-week undergraduate ID studio course in 2011. Her biomimicry research analysis and pilot-course experiences were presented at the 2012 Second Annual Biomimicry in Higher Education Webinar. The collection of the data from her research, and the knowledge gained from the online MCAD course 'Biomimicry for Designers' informed the development of her ID studio-based course.

Utilizing a "how would nature do it" theory, this educator employed a spiral design methodology to weave biomimicry into this new curriculum. The cyclical nature of the spiral was effective for weaving biomimicry into an ID curriculum for repeatability, allowing students multiple opportunities to apply BID at different phases of project development. She observed that biomimicry, which requires students to think critically about design and ecology, is a methodology that could benefit a variety of topics in her department's program.

The educator believed that most of the courses in an ID program could integrate biomimicry strategies, that students tend to transfer SD practices from one course to other courses, and the best to least effective teaching strategies would be:

- field study: as it is hands-on allowing nature do the teaching
- studio: as students bring what they learn in nature into studio discussions
- labs: as they allow students to explore biomimicry on their own

The interviewee stated that the Biomimicry Institute's database AskNature is a key resource for student investigations into biological processes. As well, important to the coursework are collaboration skillsets, in-class competitions, and various biomimicry application concepts provided by the Biomimicry Institute website.

It was her opinion that only 1 of 5 ID educators understand biomimicry, and find it overwhelming, believing it the reason why it is not taught in other departments where she teaches. When asked about her greatest challenges once deciding to introduce biology into the design curriculum, this educator responded that she believed there was general lack of awareness about biomimicry across the faculty and student body. Communicating new ideas, according this educator, needs more attention when knowledge building and crossing boundaries. The interview concluded with the insight that, although it is possible to deliver biomimicry as an online model to undergraduate students, it is better suited at the graduate level due to its complexity and the ability to think critically about it in a design context.

4.2.2 Interview 2 - U.S. Participant

This interviewee is an ID educator who has been integrating BID into an ID design program for more than five years. Following the clarification of two survey

question answers, the discussion turned to her experiences regarding the application of BID and biomimicry strategies and challenges.

The educator utilized two key biological concepts when teaching biomimicry. Firstly, 'fractals' (Figure 16 & Figure 17) according to the educator, is an idea generator and visualization tool that the educator uses to illustrate the biological concepts of design patterning, and ecological equity and balance to students. McDonough and Braungart (2002) use fractals as tool for concept development when examining and weighing the various design criteria in the IDP process. Each design suggestion is valued equally when assembled as a whole (McDonough & Braungart).

Figure 16: Sierpinski Triangle
Removes the middle triangle from the prior generation is an example of a fractal-inspired repetitive design pattern. (FractalFoundation.org, 2009. Used with permission.)

Figure 17: Examples of fractal patterns in nature
(FractalFoundation.org, 2009. Used with permission.)

Secondly, 'parametric design' (Figure 18) is an effective concept for learners to tie nature and patterns together according to the interviewee. Parametric design is the methodology of using repeatable forms in manufactured products and building design,

informed by nature's fractals (Zakout, 2013). Gehry's design for the Walt Disney Concert Hall is a prime example of the use of parametric design principles in architecture.

Figure 18: The Walt Disney Concert Hall
Designed by Frank O. Gehry & Partners - an example of fractal patterns when using parametric design in architecture. (Philipp Rummele. Used with permission.)

The educator interviewee believed that idea of a stand-alone course was the better way to introduce biomimicry, and such a course is under consideration by a peer in another design-related faculty. Teaching biomimicry as a stand-alone course, she observed, would allow the educators and learners to discuss and practice the principles with more depth. However, the institution where she teaches does not have the faculty members sufficiently versed in biomimicry to teach it as stand-alone course at this time. Lastly, the educator believed that this is one of the impediments to advancing biomimicry in academia and at the institution where she teaches.

4.2.3 Interview 3 - Canadian Participant

The first of the two Canadian interviewees is an educator in the Department of Art in a Design & Communications. She teaches graphics and communications to engineers at both the undergraduate and graduate levels. This educator first introduced biomimicry to students in 2004.

The educator believed that an in situ experience was an ideal vehicle for introducing biomimicry to learners. For example, a visit to the zoo is an effective strategy especially when paired with an online database like AskNature (Biomimicry Institute) where the students can reference examples of how biological functions translate into design innovations. Researching an animal or organism helps a learner to understand biological characteristics and the design principles applicable to other design challenges. As well, looking into the core (inside of how something works) and the actions that makes an object function, i.e., bank machine, gas pump, vacuum cleaner is an example the interviewee uses as an analogy when teaching natural versus mechanized processes to students.

When asked if there was any course analysis conducted on these specific challenges, the educator admitted that “so far time has not permitted to reflect on studying the outcomes”, especially with such a large student body in the courses she teaches. She commented that intermingling disciplines and measuring outcomes are the challenges she most struggles with as an educator teaching biomimicry.

This educator suggested introducing biomimicry and interdisciplinary concepts to students as early as possible as they carry forward their acquired knowledge. In closing, this educator stated that in her experience “biomimicry fills the space between

the disciplines". To me, this observation was reminiscent of Jane Rendell's writings about transitional 'space' in *Site-Writing –The Architecture of Art Criticism* (2010). To Rendell, transitional space is not a place but the intersection where ideas converge, and discovery occurs. Biomimicry provides that 'space' for multiple disciplines to converge and innovate in collaboration to create ecology-positive design solutions.

4.2.4 Interview 4 - Canadian Participant

The second of the two Canadian interviewees is an ID educator in who has been integrating LEED and green building strategies in an ID program for more than five years, but no BID topics. When asked if the educator could foresee the program that she teaches within integrating BID strategies or biomimicry in the future, she replied "not at this time". She reasoned that the institution focusses on the Ministry of Education requirements of prescribed core courses, non-core courses, and electives (open for any students), and for that institution biomimicry was on that list. The educator believes that faculty members prefer to strive to meet versus exceed pedagogical curriculum requirements. Their college mandated that 20% of their courses be offered online so is focussing on that directive based on existing pedagogy as opposed to introducing new (complex) course topics. This educator believes that biomimicry should be a stand-alone course as is not a subject not easily understood by teachers or students. 'Educate the educator' was her suggestion.

Dedicating more course time to reflect on BID concepts would deepen comprehension and application success rates, based on her experience. This educator's strategy for teaching biomimicry at her institution would be to develop a

course that blended students from multiple disciplines so they could contribute their own unique problem-solving strategies while developing collaboration skill sets.

4.2.5 Semi-structured Interview Conclusions

The one-on-one interviews attempted to fill any gaps resulting from the questionnaire responses, and this section summarizes those discussions. Common threads, insights, and advice towards biomimicry curricula development follow.

Firstly, the interviewed educators expressed that students find new topics like biomimicry invigorating, and once informed, educators should introduce it with confidence that the majority of students will be excited about it. They suggest that institutions need to be open to new ways to feed learner curiosities, support faculty member continuing education requirements, attempt to advance institution commitments in meeting sustainability goals, and advance multidisciplinary opportunities.

Secondly, the interviewees suggested similar methodologies for teaching biomimicry. Introducing biomimicry as a methodology to advance healthy interior environments would be an effective transition into the subject. The interviewees that teach biomimicry suggested integration techniques that included:

- field study and hands-on exercises that engage learners with nature
- visuals that illustrate biomimicry concepts to learners including case studies, design patterning, and parametric design modeling
- charrettes and in-class competitions that increase collaboration skillsets once students become more familiar with biomimicry concepts

- case studies and access to online resources that illustrates examples of nature-to-design symbiosis
- a common language for multidisciplinary interaction and teaming

All of the educators surveyed believed in the importance of including as many disciplines as possible when teaching biomimicry in order to model nature's interdependencies. One educator from Canada suggested that an 'inquiry-style' pilot course might be a good first step for introducing a BID course into their curricula, and three of the four interviewees volunteered their support and participation towards its development. Two of the four educators I interviewed believed that if students are able to competently comprehend and apply biomimicry in one course, that they will apply that knowledge with them into other coursework, and will influence their evolving worldview.

Although the questionnaire resulted in responses about studio-based learning in the U.S. and lectures in Canada as the primary teaching methodologies, it is curious that field study was the least used format for biomimicry integration. Three out of four educators interviewed believed immersion in nature to be the best way to introduce biomimicry to their students. These interviewees believed that students respond positively to biomimicry and learn to appreciate nature the more they are exposed to its lessons in situ. The survey analysis did not reveal the basis for the disparity between the questionnaires, where outdoor study was the least used setting for teaching biomimicry, as opposed to it being the ideal setting according to the interviewees who teach it.

Perhaps the most revealing suggestion from all of the interviewees was the common appeal for the creation of a vehicle to 'educate the educators' in biomimicry.

This phrase repeated in all of the four interviews and was the most revealing outcomes of this study. Canadian questionnaire respondents and interviewees stated that introducing new topics into existing curricula is a 'professor-driven' versus 'program-driven' initiative. The interviewees suggested the development of a readily accessible professional development course, workshop and/or massive open online course (MOOC) in biomimicry, complete with accreditation and certification opportunities, available at low or no cost. The interview participants strongly believe that for educators to teach complex, cross-disciplinary subjects, such as biomimicry, they would need to acquire a thorough understanding of the topic, its applications, and a structure for repeatability. However, it was unanimous stated by all interviewed educators that educators need to be the impetus for introducing new concepts into their curricula, and champion the integration of leading-edge topics within their departments.

4.3 Precedent Study: BID and Biomimicry Curricula

To further the survey findings, this last section of the chapter describes seven courses that exhibit BID methodologies and/or are biomimicry focussed, two of which were from the same program. Five of the courses originated out of the U.S., and two from the same institution) are in Canada. All of the courses were (or are) taught on-campus, with the exception of one course that is delivered online, and are at an undergraduate level unless noted otherwise. Five of the precedent studies were a result of the literature review research and were studies framed around the respective course with the exception of the online course. The course selection strategy provided the precedent studies with a wide berth of knowledge about the courses, including their development and teaching theories, instructional methods, and outcomes. The

Canadian courses were the outcome of my investigation into biomimicry courses (in Canada) when looking for elective courses to fulfil the requirements of my graduate degree. The university was within a reasonable travel distance to enable me to visit the campus, meet the department head, and learn more about the courses than I would have through online research only. As discussed in the literature review analysis, there was a deficient amount of research data available online (as compared to the U.S. studies) about BID education in design disciplines in Canada to include in this precedent study.

The precedent studies are organized in chronologic order to illustrate the evolution of biomimicry course development, each selected based on their relevance towards advancing ID curricula. The Biomimicry Institute's BEN web portal hosts an example of the online curriculum for one of their certificate courses. Syllabi for on-campus courses was generally unavailable online for analysis as compared to the courses in the studies.

The first precedent study is unique to the others as discusses an overview of a course at Georgia Tech tracked over five years by Yen et al. (2012). Some studies provided more detail than others in the various common categories did, thus the course summaries vary from study to study based on the details available. According to Helms et al., "The advantage of descriptive accounts of design including realism, and accuracy of predictions of design behaviours" (Helms et al, 2009, p.608). This commentary is particularly relevant as Helms et al (2009) presented one the earlier in situ studies of an introductory course in BID at Georgia Tech as described in Precedent 1. Each course is at an introductory level, is one semester long, and involves undergraduate learners.

Most of the course descriptions are direct excerpts from the research and/or website course descriptions. A chart summarizing these courses are located in Appendix C.

Precedent 1 – BID Course Comparison: 2005-2009

Georgia Institute of Technology, Atlanta, Georgia, United States

The BID course, according to Yen et al. (Bar-Cohen, Ed., 2012; Helms et al., 2009), was designed in a multidisciplinary context based on an engineering platform. The course was a collaboration between six schools, all participating in the teaching process, from Georgia Tech's Schools of: Biology, Chemistry, Mechanical Engineering, Industrial and Systems Engineering, and Polymer, Textile and Fiber Engineering. The authors of the study were the course designers and instructors (J. Yen, personal communication, November 27, 2015). Yen and Weissburg, are professors in the School of Biology, and Goel and Helms are professors in the School of Integrative Computing, Design Intelligence Laboratory (CBID, 2015). Not only is it one of the first BID course trials in North America but research conducted by Yen et al. (Bar-Cohen, Ed., 2012) chronicled the course development from its inception in 2005 to 2009 (Figure 19). This course, delivered annually, was constructed to learn how biomimetic principles could provide innovative problem-solving options for design challenges, and identify:

- novel techniques for creative design
- interdisciplinary communication skills
- knowledge about domains outside of their own
- qualities unique to interdisciplinary collaboration
- application strategies of the student's discipline-specific technical skills to a new discipline

Evolution of Undergraduate BID Course at Georgia Tech, 2005-2009

Year	2005	2006	2007	2008	2009
Students	4/12 from biology	10/45 from biology	10/45 from biology	20/45 from biology	20/40 from biology
Assessment Metho-dology	Classroom observations	*In situ* cognitive study	In-class experiments, mechanical engineering class experiments	Classroom observations	Analysis of final portfolios
Findings		Observations of design fixation and solution-versus problem-driven processes	Observations of: different representations among different groups; use of compound analogy; enhanced variation in designs	Student comments reflecting disbelief in real-world value of process, proof-of-concept experiment design requires new skills	Students express greater satisfaction with final designs repeated practice embeds BID process
Changes	Initial seminar (two credit) class, found objects, idea journals	Expanded to a full three-credit course, full interdisciplinary cross listing, reduced duration of expert lectures to achieve balance between content and process education	Incorporated solution and problem-driven process, structure behaviour function (SBF) lecture, functional decomposition	Increased emphasis on ideation, changes to SBF language, analogy emphasis, restructured design project	Three design iterations to embed BID process and increase ideation, structured feasibility analysis to increase conceptual understandin g and address perceived lack of real-world value

Figure 19: Analysis of outcomes from BID course at Georgia Tech (adapted from Yen et al, 2012, p.334, by author)

Key observations of the study were that:

- BID is inherently interdisciplinary
- a common language is required for disciplines to communicate
- each discipline has their own perspectives, processes, and resources for application (and different from those in nature)
- bio-inspired designs result in more multifunctional interdependencies than engineering discipline alone

When measuring outcomes, the study was less concerned about the pedagogical approach and learning outcomes, and more interested in observing designers engaged in the BID process (less 'what' they learn, more 'how' how they learn). Outcomes were:

Designers use two distinct starting points for BID

Although problem-driven is the presumed methodology as normative for BID, a solution-driven approach emerged in practice by 4 out of 9 design teams. Approximately half of the students were receptive to the integration of biology in the design process, while some teams believed it added to their problem-solving challenges. Considering the diversity of the student disciplines, their vernacular and specific skill-sets, this is not a surprising outcome.

Regular patterns of practice emerge in BID

Several patterns of practice evolved during the team design process including: focussing on structure over function; design teams locked onto solutions discussed during presentations; and while some teams claimed that biology provided too many possibilities other teams found the opposite.

Common errors occurred in regularity during the design process included:

- vaguely defined problems
- poor problem-solving pairing
- oversimplification of complex functions
- using ‘off-the-shelf” biological solutions
- simplification of optimization problems
- solution fixation
- misapplied analogy
- improper analogical transfer

This five-year study produced findings that articulated valuable feedback as to how interdisciplinary students learn and what is important to advance BID education. Yen et al. identified that: (a) interdisciplinary make-up of student teams affected the outcome and subsequently the curriculum developed increased the percentage of biology students, (b) the importance of repeatability, and (c) diagrams were a better utilization tool than text. According to Sarkar & Chakrabarti, visual tools resulted in a greater quantity and quality of design solutions (as cited in Helms et al., 2009). Lastly, it was determined that the interdisciplinary student project teams with the greater diversity of disciplines provided the broadest and more balanced outcomes. This Bio Inspired Design course remains the foundation of their CBID program today (CBIN, 2015).

Precedent 2 - Biomimicry: Towards a Sustain-Able Design

Sam Fox School of Design & Visual Arts

Washington University, St. Louis, United States

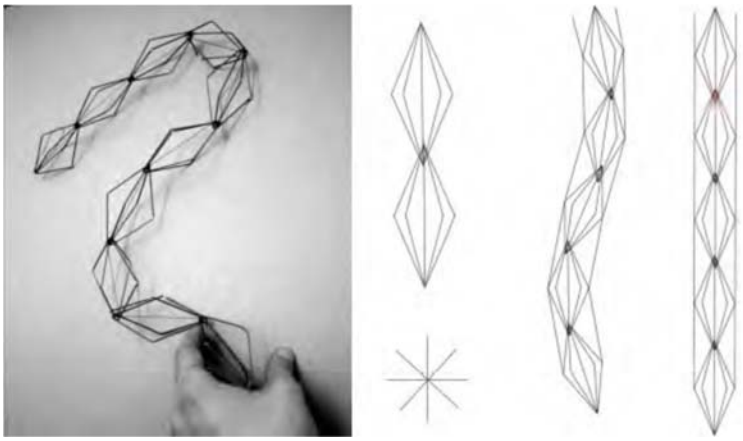
This course, first delivered in 2010, assembles collaborative teams of students from various disciplines including biology, engineering, and architecture (Freixas, 2011). The course was based on the premise that buildings have diverse effects on their environment during their lifecycle, when viewed through an ecological lens from the onset. The course goal was to create environmental awareness for the student and increase their ability to design sustainable buildings by using the biomimicry principles of nature as model, measure, and mentor (Benyus, 1997). Freixas explains the intended outcomes as:

- discovery: students locate natural organisms with particular characteristics that will contribute to their problem-solving challenges which encourages responsibility for maintaining the integrity of nature's design
- independent thinking and research: students are free to choose the organism of study, and through dissection and research identify potential applications in the built environment
- collaboration: through teaming with various disciplines and academic levels they learn from each other, and borrow from each other's strengths
- biomimicry methodology: through investigation students learn a fundamental respect and understanding of nature's design

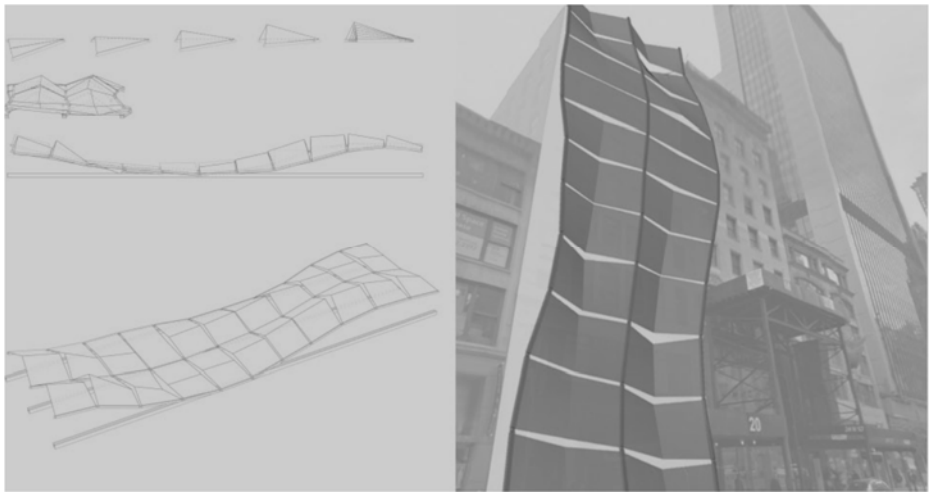
This multidisciplinary course teaches students through lectures (including guest lecturers), pin-ups of design iterations, reviews, and workshops. According to Freixas

(2011), the focus of this course examined interdisciplinary collaboration and solving real-world problems using biomimicry. The student project profiled in this precedent study, known as the Sidewinder Project (Figure 20), employed ideation, graphic deconstruction of organisms as they related to their problem-solving, and modeling.

A. Image of Sidewinding Snake (rcreptiles.com)



B. Sidewinding Project - Model 2



C. Sidewinding Project - Double Façade Ideations

Figure 20: Biomimicry project development based on the Sidewinder snake.
Sidewinding Project models and ideations by students P. Hernandez, T. Johnson, & D. Tish
(Freixas, 2012. Used with permission.)

The educator/researcher noted that Life's Principles (Biomimicry Institute) were used as guidelines for the students' biological lens. Following an introductory biomimicry

lecture and video, the students were required to self-assemble into teams including undergraduate and graduate levels and disciplines. Students employed a combination of strategies to investigate and understand their chosen organism on macro and micro levels, and 'feedback loops' encouraged the students to continually revaluate their utilization theories throughout the design process.

The course resembles a design studio format, and presents a course curriculum that could better transition into an ID pedagogy than the biomimetic course from Georgia Tech (Precedent 1) that originated from an engineering-based curriculum. There are no inferences as to the research tools that were employed, however, the inclusion of biology students within the project teams would have contributed to the students' scientific investigations and understanding of biological processes and functions. This course challenged the students to develop democratic ways to work with a cross-section of disciplines and problem-solving methodologies, and to not only consider the impact of their design on nature but the nature of their design.

Precedent 3 - Undergraduate Interior Design Course

Art Institute of California – Inland Empire, California, United States

Unlike the previous courses profiled, this was a biomimicry studio course specifically for ID students that was launched in 2011 as a course pilot. Angne (2012) not only integrated biomimicry into its curriculum but also looked to nature to guide the development of this 11-week course. A component of the study surveyed ID educators to learn: (a) does academia really understand biomimicry as an advanced sustainable design strategy, and (b) are there more effective ways to integrate the biomimicry or maximize outcomes? From those research findings, Angne developed a course

curriculum utilizing a teaching idea, inspired by nature, to integrate biomimicry in a cyclical format (Figure 21).

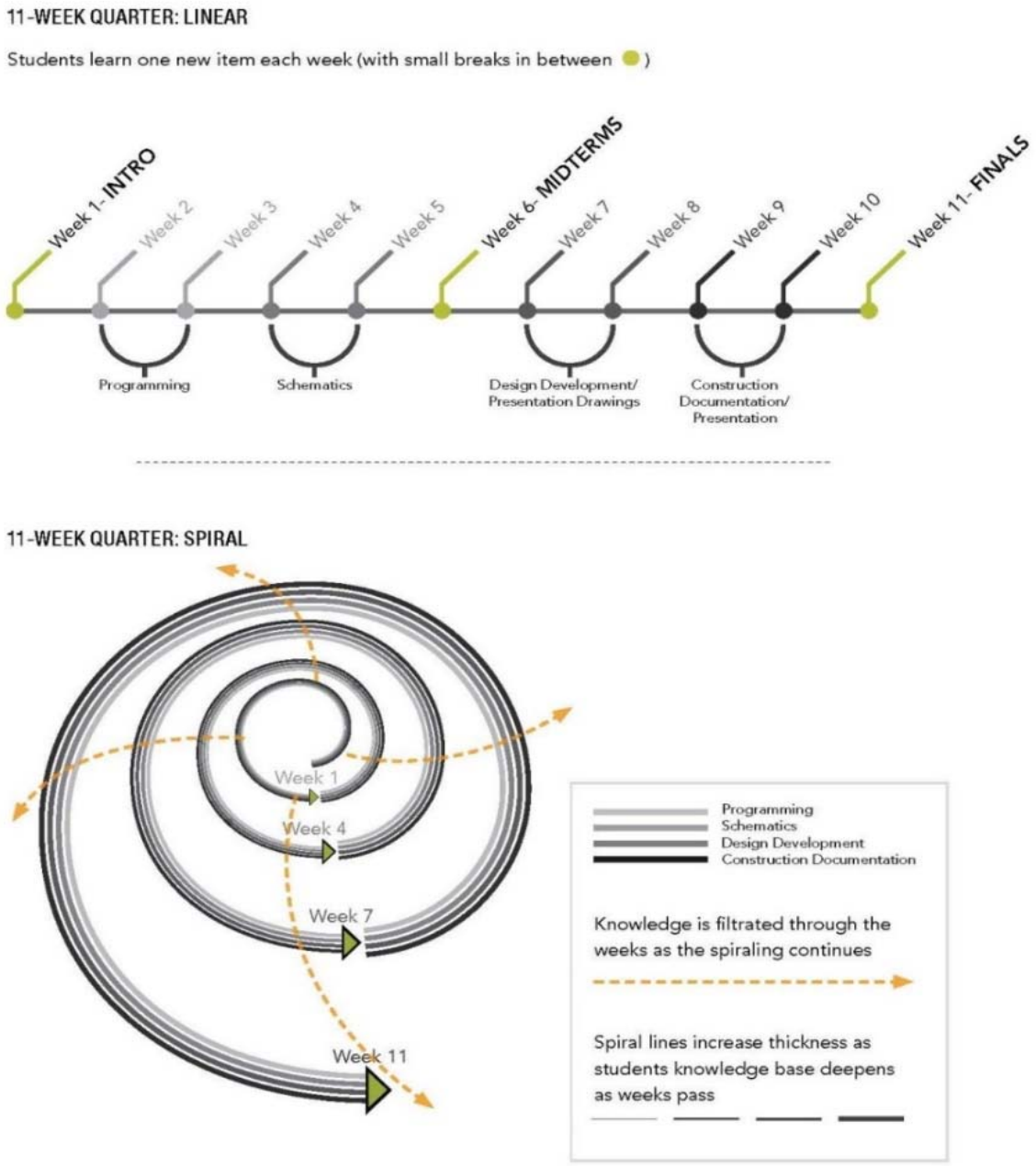


Figure 21: Integrating biomimicry into an interior design studio
(Angne, 2012. Used with permission.)

Angne's research for the course was influenced by Rossin's (2010) theory where "the application of biomimicry principles during the design process will move the

designer into a new era of sustainable applications, technologies and approaches" (as cited in Angne, 2012, p.3). The methodology of integrating biomimicry principles and strategies repetitively throughout the semester offered a way to regularly monitor the level of student comprehension, reinforce the principles, and contribute to the repeatability of the concepts, was documented in the study including observations and outcomes. Angne's premise for her ongoing course development resonates from Benyus' theory that "the more people learn from nature's mentors, the more they'll want to protect them" (as cited in Angne, 2012, p.2). Angne's lessons learned were that:

- Valuable resources for students include: Biomimicry Institute; TED Talks; project based research and problem-solving; interdisciplinary labs with biologists
- Many CIDA standards, required for accreditation, are satisfied when integrating biomimicry into ID curricula.
- Two cyclical terms better fit in an 11-week course, and 3 cyclical terms better suited to a 16-week semester.
- There is not one path but many combinations of BID teaching methodologies to provide the right pedagogical fit for an institution.
- Biomimicry requires interdisciplinary teaming which could be the bridge to connect interior designers with biology.
- A certificate program combining biomimicry and ID may evolve at her institution once the current course is further developed.

Based on her biomimicry research, and ongoing assessment of the curriculum and teaching methodologies, Angne has continued to develop and teach the course to ID students in the course offered at the Art Institute of California.

Precedent 4 - Transdisciplinarity and the Sustainability Curriculum

Arizona State University, Tempe, Arkansas, United States

Kansas State University, Manhattan, Kansas, United States

Oklahoma State University, Stillwater, Oklahoma, United States

This introductory course is a collaboration of tri-institution collaboration educators (Remington-Doucette, Connell, Armstrong & Musgrove, 2013) based on a curriculum developed by three educators from three different institutions. Through a pre-/post-test curriculum assessment strategy, this study theorizes that institutions need to observe the importance of transdisciplinary affiliations and sustainability competencies. The authors believe that transdisciplinarity builds on multidisciplinary collaboration by extending education into a "wider community of stakeholders" outside of the university walls (Scholz et al., Stauffacher et al., Brundiers et al. & Brown et al. as cited by Remington-Doucette et al., 2013, p.2). The course development followed key competencies examined through the lens of transdisciplinarity and a sustainability curriculum. Remington-Doucette et al. studied the way that multidisciplinary collaboration, which included community involvement, could blur the confines of individual problem-solving approaches in sustainable challenges in "real-world scenarios" (p.2).

Competencies observed were:

- Systems Thinking is problem-solving concept with an ecological basis for understanding how a system that functions as a whole, for example a tree (photosynthesis) or a digestion system. The goal was to understand the whole and the interrelationships that combine to create a cohesive entity and, in turn,

transfer that knowledge of how systems relate into a problem-solving strategy. The students, based on a set of ecological values, were required to identify and critically reflect on how the components could apply for one outcome.

- Normative thinking (an ideal standard or model of thinking), which the study describes as “an assertion of values and ideas of what the world should look like”, involves projecting a future ideal pertaining to the way the world should target sustainably (p.4).
- Strategic Competence which involves engaging with stakeholders to realize their respective values, preferences and beliefs; to have the ability to collectively design and implement “interventions, transitions, and transformative strategies” to steer ideas on sustainability (p.4); and to recognize the hurdles, real or perceived.
- Sustainability Competency, through the exploration of case studies. Remington-Doucette et al.’s (2013) research found this to be to be a popular teaching methodology particularly when integrating advanced sustainable principles and cite other related studies in their research by Barnes et al., (1994); Stauffacher et al., (1994); Scholz, (2006); and Wassermann, (2006).

Doucette et al. assessed the course and student performance, and identified the following outcomes:

- Business majors did not improve any key competencies
- Sustainability majors improved systems thinking competence only
- Sustainability minors improved all competencies

- The lack of success in all but Systems Thinking for Sustainability majors is thought to be that they don't have a grounding in a discipline and therefore do not have evolved conflict resolution skills
- It is unclear as to whether infusing sustainability or teaching stand-alone is better (found dependant on the background of the students)
- It's not straightforward exactly what should be taught
- One roadblock to interdisciplinary education for students is a lack of control "over their own turf"

Observations of the researchers highlighted that some institutions debate their ability to deliver interdisciplinary or transdisciplinary pedagogy when boundaries between the disciplines need to be blurred. Boix Mansilla (2005) of Harvard's Project Zero waste reduction initiative states that creative problem-solving is at its best when diverse disciplines collaborative and share expertise (as cited by Remington-Doucette et al., 2013, p.2).

Remington-Doucette et al. identify recommendations for future course development. Firstly, education needs to utilize case studies (involving collaboration between students, practitioners and community stakeholders) to a more advanced degree. Secondly, survey students to better understand their reasoning for choosing their selected majors. Lastly, ongoing assessment is required to understand the success of this program, the methodologies, and whether transdisciplinary, multidisciplinary or interdisciplinary methodology is more relevant. The authors strongly believe assessment should occur throughout each student's university sustainability

education to ensure that the courses taken alongside sustainability reinforce, challenge, or contrast sustainability principles.

Precedent 5 – Learning From Nature: A Course in Biomimicry

The Sustainability Leaders Network, Hartland, Vermont, United States

The Biomimicry Institute's BEN website offers numerous curriculum models for a broad spectrum of learners, from kindergarten to graduate studies and beyond. BEN provides a link to this free 12-week course, suitable for university students, available through the Sustainability Leaders Network (SLN). This global network is a collaboration of "sustainability champions" from academia, art, agriculture, engineering, communication technology, and human services. This core team came together to strengthen and inform the biomimicry movement among educators and learners locally and around the world. SNL created this, and other courses, based on theories from leaders in sustainability such as Donella Meadows, Buckminster Fuller and Janine Benyus, among others. "The more our world functions like the natural world, the more likely we are to endure on this home that is ours, but not ours alone" states Benyus on the BEN website (Biomimicry Institute, n.d.).

According to SNL, the Learning From Nature course is constructed on an open-source curriculum from that utilizes a systems thinking approach towards sustainability. This curriculum model allows for an open exchange of ideas from other ecology-minded thought leaders and followers, which SLN believes promotes idea generation and innovation. This course offers an introduction to biomimicry and lessons on how to learn from nature. The course curriculum emphasizes the importance of outdoor experiences and exploring the learner's natural world. The biomimicry curriculum that

SLN has designed, tested, and refined, concentrates on observing, appreciating, and learning from nature and natural systems. Cognizant of the ways in which consumption and population growth have degraded our environment, according the Biomimicry Institute, this course focuses on nature's lessons, and ways to take meaningful action in the preservation of our natural world. The curriculum is flexible in terms of content and structure, encouraging adaptation to local surroundings and their unique bio-diversities, and getting students outside as much as possible. Although no course outcomes are currently documented, the Sustainability Leaders Network requests that feedback be submitted at the course conclusion based on successes and lessons learned so that, like nature, the course curriculum can adapt and evolve with each generation.

Although this course provides educators with an introductory in-class curriculum in biomimicry, BEN also offers a cross-section of educational models, including graduate-level course, in association with Arizona State University that offers a blended format combining online and *in situ* learning streams.

Precedent 6 – Biomimicry 1 - Points of Departure

Precedent 7 – Biomimicry 2 - Application

Ontario College of Art University (OCADU), Toronto, Canada

Biomimicry 1 - Points of Departure and Biomimicry 2 - Application are unique courses compared to courses in the precedent studies in that:

1 - Each course is one semester in length and solely based on biomimicry

2 - Biomimicry 1 is the prerequisite for Biomimicry 2

3 - They are stand-alone biomimicry courses (of which others are not in Canada)

According to the head of the Environmental Design department, Bruce Hinds, the courses are modeled on a systems-thinking approach to biomimicry application that result in evidence-based outcomes (personal communication, November 5, 2013). These biomimicry programs are collaborative and are open to all students.

'Biomimicry 1: Points of Departure', is a course that "provides a practical overview of the principles and current key issues related to biomimicry; the concept of using ideas from nature and transferring them to other domains such as structural design, new materials technology, sustainability, and engineering" (OCADU, 2014-15, n.p.). The course design informs students of alternative sustainable options for solving human problems and interactions between form and function. The curriculum is project based, and focuses on principles and processes that address minimizing material and energy consumption through self-sustaining and self-renewing qualities.

'Biomimicry 2: Application', provides BID opportunities for students to apply the principles learned in Biomimicry 1 for the design of innovative products, structure, and systems. Students are required to form collaborative teams and, through participation in design competitions, practice the learned principles and processes in in a real-world context.

In addition to the biomimicry courses, OCADU offers several aligned courses, and interdisciplinary and collaboration workshops. They facilitate an annual DEEP Think Tank conference, and through their Faculty of Design offer the think tank style courses 1: Awareness, 2: Consideration, and 3: Action. According to OCADU's 'Design for Humanity' mandate, these courses compliment their biomimicry courses, providing

students with collaborative skillsets to empower them to become proactive eco-centric leaders.

The seven BID courses described in the precedent study identify a range of educational challenges including the collaboration of multiple faculties, developing a common language, and sharing of authorship or release of intellectual property. According to Becher (1989) and Cairns (2004), when stating the reasons for institutions of higher education to be resistant to integrative approaches, include such factors as "territoriality, academic tenure reward structures, and external funding opportunities" (as cited by Remington-Doucette et al., 2013, p.3), which is consistent with the survey results reported in Chapter 4. Intermixing disciplines is important for teaching biomimicry concepts, particularly when the teaming includes biology students due to their knowledge of nature's processes for regeneration, their discipline-based expertise in problem-driven methodologies, and their insights into the world of bio-organisms. A multidisciplinary student makeup is the preferred biomimicry methodology for active learning, and educators learned that the student teams experience a higher level of creative problem-solving. Ross (2015), a Visiting Fellow at John Hopkins University, states that "… while we need specialization, the breakthrough thinkers of the future will be able to combine an understanding of things [from various domains]" (pg.7). He believes that when the students from divergent disciplines merge they will be the new inventors of industries that do exist today.

Whereas the precedent research revealed that due to the quantity of content and faculty limitations biomimicry, not all agreed. Researchers and educators argue that the better approach is to integrate BID pedagogy into all related courses to reinforce,

challenge, or contrast sustainability principles (Remington-Doucette et al., 2013; Angne, 2012). A stand-alone course in biomimicry, such as at OCADU or through SLN and BEN, may be the better approach to advance learner comprehension and application for a wider variety of learners. This course structure would allow students to immerse in the subject delivered by an educator that is a biomimicry expert or one with more experience integrating complex science-based subjects than other educators. It may as well become a course open to many disciplines and therefore provide more cross-disciplinary opportunities than in a traditional ID program.

The importance of designing repeatability into a curriculum was an essential component. The research studies that monitored these courses teaching BID and biomimicry, observed that the students' ability to track and repeat the biomimicry processes was important to the improving their cognition and competencies. The course studies concluded that a combination of strategies to advance cognition in combination with a systems thinking approach was an effective approach when introducing biomimicry. The curricula researched illustrated that for learners to embrace biomimicry, a problem-driven exploration process be adopted, where the focus is on the journey versus the destination. Assessing curriculum strategies and learner outcomes contributed to the evolution of teaching techniques with an evidence-based platform. This phase of research uncovered a variety of BID integration models and the linkages between the courses were clear: establish a common language, utilize systems thinking concepts, include as many disciplines as possible, and make time for ongoing iteration and reflection.

4.4 The State of Biomimicry Education for ID Educators

In 2005, the United Nations established the Decade of Education for Sustainable Development (DESD) "with the goal of supporting the incorporation of SD into courses and curricula through the world" (Lozano-Garcia, Gandara, Perrni, Manzano, Herandez & Huisingh, 2008, p.257). Ten years later, what is the state of SD education?

In 2005, Georgia Tech was the leader in integrating biology into interdisciplinary STEM student teams as reviewed in the Precedent Study 1. Today CBID at Georgia Tech has expanded its stakeholder partnerships connecting at least eleven schools that include the sciences, technology, architecture, engineering, liberal arts, environmental, bio-robotics, textile and fiber engineering, plus related practitioners and fellows. BID remains the baseline for CBID research, and focuses in the "development of design solutions that occur in biological processes" (CBID, 2015). Over the last decade, a number of institutions have followed their lead, and in 2006, Arizona State University (ASU) established the first School of Sustainability in the U.S. Today, ASU and MCAD are two U.S. post-secondary leaders in biomimicry education. MCAD leads the charge in graduate-level biomimicry education when it launched a 36-credit Master of Arts in Sustainable Design program in 2012. ASU debuted a 30-credit Master of Science in Biomimicry in 2015. Both programs' course structure are themed into the primary categories of theory, practice, and leadership (Figure 22), and are members of the Biomimicry Institute's Affiliates Program. Both schools involve no less than two Biomimicry Fellows, as is required as part of the Affiliates Program criteria and both programs are delivered entirely online. Figure 22 outlines the two curricula, how each integrates biomimicry. Although both programs indicate biology-inspired pedagogy, the

ASU degree program clearly delineates the contrasting course content between sustainable design and biomimicry education within this comparative framework.

	Minneapolis College of Art and Design (MCAD) (MA) Sustainable Design 2012 - online 36 credits	**Arizona State University (ASU)** (MS) Biomimicry 2015 - online 30 credits
Theory	Introduction to SD Systems Thinking Making a Business Case for SD Nature's design rules for sustainability Ethics-based marketing	Essentials of biomimicry Life's Principles Biology Taught Functionally Biomimicry Thinking Human-Nature Connection iSites
Practice	Innovation Tools & Techniques The Practice of SD Collaborative Product Design Global Design Challenge Biomimetic Design Packaging sustainability	Biomimicry in Design Biomimicry in Engineering Biomimicry in Business P - Biomimicry Case Study P - BioBrainstorm P - Biomimicry Genius of Place P - Virtual Design Lab
Leadership	Creative Leadership Visual communications for sustain... Design for community Design for global change	Communicating Biomimicry Teaching Biomimicry Facilitating Biomimicry
	- requires practicum and thesis project	- requires 4 practicum projects

Figure 22: U.S. institutions currently integrating biomimicry into their graduate curricula (by author)

Within these three key categories of theory, practice, and leadership, courses based on nature in design, collaboration, communication, and outreach are common to both programs. The programs' structures reinforce the biomimicry awareness and competence, such that graduates have the acquired skills to pay forward an enhanced environmental worldview. The ASU degree indicates how influential science is in a biomimicry program as exhibited earlier in this thesis research. ASU's School of Sustainability also offer undergraduate programs, including a Biomimicry in Design

course. Biomimicry is strongest when multiple disciplines collaborate, and these courses benefit from a wide cross-section of students, with biomimic goals.

Today, BID and biomimicry education is available from a growing number of educational sources. "The rapid growth of the movement of BID has led to a rapid proliferation of educational courses and programs for learning about the paradigm" (Goel et al., 2015, pp.215-216). Additionally, several professional associations and organizations that collect, and disseminate BID education and biomimicry innovation strategies. Courses for IDC registered practitioners and educators to acquire their continuing education units (CEU), also provide professional development opportunities for academics seeking new knowledge. Figure 23 outlines a cross-section of the resources that: (a) address SD, BID, biomimicry, and/or C2C-inspired design topics, and (b) that are accessible to the majority of Canadian learners, including educators and industry partners.

Of the various organizations supporting biomimicry, the Biomimicry Institute leads the movement. This organization not only is the nucleus for biomimicry research and innovation but also offers the broadest range of educational curricula, training, and tools available online today. AskNature, owned and managed by the Biomimicry Institute, is potentially the most accessed nature-inspired design databases available to the public in the world.

Examples of organizations providing various forms of regenerative design education available to Canadian HE learners, pertaining to course content that integrates biomimetic, cradle2cradle, or ecologically positive pedagogy.	Targeted Learners*					Delivery Models					Comments
	members	educators	practitioners	all learners	other	conferences	workshops	webinars	MOOCs	other	
Interior Design Educators Council (IDEC)		✔				✔	✔			1	hub for interior design education
International Interior Design Association (IIDA)	✔	✔	✔				✔	✔		2	hub for global course options
Environmental Design Research Education (EDRA)	✔	✔	✔			✔	✔				knowledge network to promote education design research
Canadian Green Building Council (CaGBC)				✔	A	✔	✔	✔			partners with HE institutions
Green Building Research Institute (GBRI)	✔			✔	B			✔			asynchronous 1-2 hrs. per session
International Living Future Institute				✔		✔	✔	✔			disseminates research, education and case studies
Biomimicry Education Network (BEN)**	✔			✔				✔		3	curricula materials & support
Biomimicry 3.8 - Professional Pathways			✔	✔			✔	✔		3	2yr. asynchronous certificate program
Biomimicry 3.8 - Fellows Program		✔			C		✔			4	1 wk. in situ workshop
Biomimicry 3.8 - Affiliate Program		✔			D						program length is institution specific
Buckminster Fuller Institute				✔						5	research based
Ellen MacArthur Foundation (UK)				✔		✔		✔	✔	4	offers professional course; MBA in c2c; and curricula tools
Sustainable Brands				✔	A	✔	✔	✔			case study resource
Canvas Network & edX (digital education libraries partnered with global educators and institutions)				✔					✔		self-paced; wide range of topics offered (many free)
Philadelphia University (US)				✔					✔		8wk. free course
TOTAL (based on examples within the chart)	**4**	**5**	**3**	**9**		**6**	**8**	**8**	**3**		
CANADIAN POST-SECONDARY INSTITUTIONS: Institutions generally offer faculty development courses (often pertaining to curricula or technology training) for its faculty members however there was no evidence of biomimicry course content at the time of this research. This was based on a sampling of 3 Canadian universities that claim in their online course descriptions to infuse biology into their programs. Topics and delivery models vary, however the training is generally on-campus workshops 1-2 hours long and/or short-course summer sessions.											

Notes:
* learners of higher education (HE), including educators
** 11/260 global members are Canadians
A - includes industry partners; administers LEED in Canada and the Living Building Challenge
B - delivers LEED specific topics for CE exam preparation and maintenance
C - enables 2 or more faculty members to affiliate their institution with the Biomimicry Institute
D - an institution qualifies for affiliate status if there are 2 or more biomimicry fellows
1 - also disseminates research and the Journal of Interior Design
2 - disseminates research
3 - coordinates a professional forum and publications of various themes on a global basis; co-facilitates conferences
4 - includes videos and curricula activities
5 - organizes Design Science Lab (7-10 day interdisciplinary immersion workshop); hub for design science research
c2c denotes cradle to cradle
MOOC denotes massive open online course (some are free; some are not but are certificate or degree granting)

Figure 23: Professional development resources: Biomimicry for Canadian ID educators (by author)

The Biomimicry Institute through its BEN, Biomimicry Education Affiliates and Fellows Program, and in collaborating with institutional and industry affiliates, offers the broadest collective of biomimicry knowledge, and strategies for innovation. The Biomimicry Education Fellows are the leaders in biomimicry education within their institutions.

In Canada, the organization that connects ecology-minded practitioners and biomimics is the Canadian Green Building Council (CaGBC). The professional development offerings of CaGBC target their respective members; however, they provide educational and networking opportunities for all learners concerned with green building strategies, as well as facilitating LEED projects for its members. Central to the ID industry is the Interior Designers of Canada (IDC), who support their professional membership with continuing education on current issues, including public health and welfare. Based on my findings, most of the organizations facilitate forums to engage like-minds in networking forums to share research, leading–edge innovation, and professional experiences.

The research indicated that educators find many professional development options for BID, biomimicry, and/or C2C topics from a resource other than from their own institutions. With the growing number of online options for leaners from of many demographics to educate themselves, Canadian educators have new opportunities to acquire biomimicry knowledge or teaching tools, beyond conferences and workshops. Organizations and institutions in the U.S. and the U.K. are the prime delivery agents to date for continuing education in this area. The expanse of biomimicry studies and

resources that originated from those countries, accessible online and through digital media, largely informed this conclusion.

Based on my research, there are a growing number of online education opportunities. Learners worldwide are benefitting from online education based on its asynchronous format and the flexibility of a self-paced learning environment without the limitations of accessibility, conflicting time zones, and/or work schedules. MOOCs are often free or less expensive than the costs of traditional education. The flexibility of MOOCs appeal to many learners in particular working students, educators, or practitioners.

According to Canadian survey respondents, educators are the vehicles for introducing new topics into their curricula. Upon an examination of three universities in major Canadian cities, I learned that they do not offer professional development courses, beyond faculty-development courses, to educate their faculty in new pedagogy. Although none of those three universities delivered continuing education options directly to their faculty members, Canadian universities are becoming members of a global network of MOOC courses, for instance 'edX'. The edX MOOC delivery model is a web portal of more than 300 wide-ranging courses, and 400 teachers and staff (edX, 2015). EdX, an MOOC provider, whose U.S. founders include Harvard and MIT, partner with many prestigious institutions world-wide including McGill University and the University of Toronto, in Canada. EdX, and similar MOOC providers, permit learners to enrol in certificate courses that are either fee-based or can audit courses free. Online education appeals to a diversity of learners for these very reasons.

In 2015, MCAD launched a free, 4-week MOOC as an introductory course on biomimicry through the Canvas Network, a global learning platform that disseminates courses on behalf of its 108 academic partners. With over 2,500 students in the MOOC, MCAD is one of the growing number of colleges and universities offering free or low cost MOOCs on advanced sustainable design strategies and biomimicry. Based on my interviews 3/4 educators believe that in order to facilitate their professional development MOOCs are highly desirable vehicles to expand their knowledge of new research topics, teaching methodologies, and tools.

To understand which Canadian institutions include advanced sustainable course content, I assembled a list of the Canadian colleges and universities that offered degree granting ID programs from the internet, and the IDC website. From these lists, I charted each ID program and included a summary of their guiding principles and course delivery strategies, noting terminology that would indicate the extent of their SD focus. In 2013, my research observed that of the fourteen universities offering a baccalaureate degree in ID, three did not mention any SD course content in their program details published online. Three out of fourteen Canadian institutions note that they teach LEED in their SD programs. From the online program information, I surmised from descriptor words such as ‘science-based’ or ‘ecological’, that the courses integrated BID. Out of the fourteen Canadian post-secondary institutions evaluated for sustainable design and BID education content, the following observations were that:

- 57% noted that they teach SD strategies
- 38% noted that their courses are collaborative and/or multidisciplinary
- 21% noted LEED as the SD strategy they teach

- 14% noted that they integrate biology or science into their curricula
- 1% noted that they specifically teach biomimicry

These observations suggest that biomimicry has been slow to permeate into Canadian ID education (other than at OCADU). However, there are gaps in the available information from ID program websites, so this data may not necessarily representative of their program's current content. It is unknown as to why only 57% (8/14) of the programs teach any SD education in Canada. The 13% gap between programs that teach SD as opposed to those teaching LEED, BID, or biomimicry spurred on my research.

According to my questionnaire analysis, 9/15 of Canadian educators responded that biomimicry was taught in their curricula, overlapping with 8/15 educator respondents that noted LEED as the primary sustainable strategy. This contrasted my preliminary investigation leading me to investigate what variables might have influenced this outcome. I deduced that there was a possible deviation between the preliminary research and survey responses in that some of the participant educators were members of BEN, as opposed to CIDA or IIDEC registries. Considering the facts that the questionnaire was anonymous, and there was a year between the literature review and the ID pedagogy or that the institutions had not specifically identified biomimicry content in their courses on their websites. The commitment to teaching collaborative and cross-disciplinary skillsets, however, aligns with the course descriptions research and surveys. It was clear that ID educators across North America understand the importance of multidisciplinary teaming as an essential ingredient to the success of biomimicry collaboration.

4.5 Biomimicry Education: The Roadblocks and the Gaps

Biomimicry principles, processes, and application strategies are multifaceted, hence some of the challenges observed in this research study. This section discusses the key issues that contribute to the slow progress in utilizing biomimicry strategies in Canadian ID education, identifying the roadblocks and the gaps.

Based on my research and survey analysis, some Canadian ID educators noted that integrating new topics into their curricula perceived as unrelated to their institutions' vision was a roadblock. Research showed that a lack of motivation and support from their institutions to facilitate program changes inhibited educators from pioneering new BID topics such as biomimicry. Simply stated by one Canadian interviewee, the introduction of new topics is "professor-driven versus program-driven", and educators must champion new initiatives to advance their curricula and deliver new knowledge to their students.

The study revealed that there was not only a lack of awareness regarding BID and biomimicry among educators, but also a lack of awareness regarding this topic in other faculties within their institutions. This general lack of awareness about the course content in other faculties impedes collaboration in crossing disciplines. Based on the CBID model at Georgia Tech, there is no maximum in the combination of disciplines at the design table (Benyus, 1997). Sarkar & Chakrabarti claim that the inclusion of multiple student disciplines, beyond the STEM makeup, providing linkages to produce more diverse and balanced problem-solving outcomes (as cited in Helms et al., 2009).

As a precursor to the development of a multidisciplinary course, my research stressed the importance of a common language. It was clear with from the U.S.

respondents that understanding terminology and problem-solving strategies among the multidisciplinary courses were their greatest challenges. It was evident in my findings that the development of a communication tool that involved visuals to describe biological processes was essential for multiple disciplines to share concepts equitably.

One Canadian interviewee speculated that there might be a lack of rigor in some ID programs. Critical thinking is mandatory skillset for biomimicry comprehension and application. Schön (1995) in his discussion on 'new scholarship' discusses the "dilemma of rigor or relevance" (p.28). He explains that with a rigor of evidence-based theory and practice, problem-solving becomes a repeatable technique. Understanding and applying biomimicry in a design context takes time to practice and reflect on. Educators' survey responses indicate that there is a general lack of time to introduce new topics, evaluate curricula, and for professional development. Time may not be available for some educators and in some programs if they are steered in other institution-driven directions.

Sourcing educators that are already teaching biomimicry, as suggested by a U.S. interviewee, would be a proactive path for integrating biomimicry it into existing curricula. This may be more challenging for Canadian educators than in the U.S. due to the gaps in accurate information about biomimicry education and practice in Canada. As an example, 12 out of the 240 members of the BEN are Canadian, and out of that 12 only one is listed on the BEN website as an educator and Biomimicry Fellow. Upon further investigation, I learned that that OCADU was the only Canadian university that is a member of the Biomimicry Institute's Education Affiliate Program, having three Biomimicry Education Fellows on staff. This is just one example of the gaps in

obtaining data regarding the advancement of biomimicry in Canadian. Although my research indicates that Canadian educators are weaving biomimicry into ID curricula, this research found that there is an insignificant amount of Canadian data to support that. As of 2015, there is only one Canadian Biomimicry Seed Network out of thirty-one worldwide. Although not devoid of biomimicry educators or Fellows, Canadian teachers have far fewer models and mentors from which to learn in Canada.

Lastly, the connection between ID programs aspiring to meet CIDA criteria, and the benefits that biomimicry brings to the BOK does not seem to be apparent to some Canadian educators. ID programs preoccupied with the challenges of meeting CIDA requirements for their programs may not realize how weaving biomimicry into their curricula could satisfy several of them, as discussed in Chapter 3: Delivering ID Education. Educators from Canada and the U.S. believe that with accessible professional development, biomimicry awareness is the key to advancing this new knowledge into ID curricula.

Biomimicry is a demanding and invigorating new methodology that responds to the goals for advancing ID pedagogy articulated at CIDA's 2015 Future Vision assembly. Based on my research ID educators are becoming cognizant of their role in teaching students to take responsibility for their own development. Students will need the models and skill sets to become leaders, and embrace new technologies in preparation for the changing socio-economic future they will face. The multi-layered structure of biomimicry provides educators with a systematic process to integrate nature's lessons into their ID curricula. Utilizing a sequenced integration strategy, educators can make incremental bio-inspired shifts that attune with the future vision of

ID education. With lessons learned, the next chapter proposes methodologies for the advancement of biomimicry in Canadian ID education, and a process to educate the educators.

4.6 Lessons Learned in Biomimicry Education

This thesis research has attempted to understand the current state of biomimicry integration within Canadian ID programs. Firstly, the research discovered that although biomimicry is a strategy that some Canadian ID educators claim to be integrating into their programs, many are focused on meeting CIDA deadlines and are stretched to incorporate it into coursework. Secondly, the research suggests that Canadian ID educators may be familiar with biomimicry, they require the techniques and tools to kick-start the integration process. It is evident that biomimicry-inspired education is needed by a wider variety of learners, not all of who are ID students are in post-secondary programs. The survey investigation brought to light the need to provide vehicles for knowledge building to ID educators as well.

U.S. educators have explored many transferable methodologies for Canadian educators to champion the advancement of biomimicry education in their programs. The semi-structured interviews provided a deeper dive into the experiences of U.S. and Canadian educators who are weaving biomimicry into their programs and courses. One of the Canadian interviewees did not teach BID strategies because their program had other institution-driven priorities. This educator, however, provided perspective regarding the challenges introducing new topics could present when faculty-wide priorities take precedent. The other three interviews were well versed in biomimicry education and believed that introducing a complex new topic into curricula needed to be

professor-driven. Ultimately, the interviewees all believed that biomimicry awareness, access to that new knowledge, and educating the educator was step one.

For the reasons discussed, the research investigated the educational opportunities for the broader spectrum of life-long learning for ID professionals. ID educators, have traditionally been a blend of practitioners and educators from a variety of disciplines and expertise. ID educators, over the years, have included rendering artists, industrial designers, architects, engineers, and IT technologists, in addition to ID practitioners. This multidisciplinary combination of practioner-educators brings a valuable blend of expertise and experience to ID education and in particular SD strategies that include BID and biomimicry.

5.0 Building a Bridge to Biomimicry for Canadian ID Educators

Through this thesis research, it was determined that advancing the integration of biomimicry in Canada ID education, a conceptual framework would be required. The strategies for knowledge-building, and linking biomimicry to existing and/or future ID curricula were distilled, and are presented in Figure 24.

5.1	**Getting Started**
5.1.1	Build biomimicry awareness
5.1.2	Connect with biomimics
5.2	**Integrating Biomimicry**
5.2.1	Weave biomimicry into existing SD courses
5.2.2	Integrate systems thinking and collaboration into courses
5.3	**The Transition**
5.3.1	Utilize immersion in nature as a classroom for biomimicry education
5.3.2	Participate in biomimicry student competitions and challenges
5.3.3	Collaborate with other stakeholders to explore, debate, and develop multidisciplinary and biomimicry concepts
5.3.4	Consider biomimicry strategies for problem-solving
5.3.5	Rethink learning objectives, strategies for evaluating student progress, and developing course curricula
5.4	**Building Critical Mass**
5.4.1	Engage with the Biomimicry Institute and become a Biomimicry Fellow
5.4.2	Develop partnerships to share integration strategies, synergies and ways to broaden the stakeholder base
5.4.3	Explore biomimicry research in related industries and seek out opportunities to participate
5.4.4	Become an agent for change

Figure 24: Conceptual framework to educate the educators
(by author)

The conceptual framework is the culmination of that research, lessons learned and advice provided by educators who weave biomimicry into their programs. Based on Bloom's (1956) curricula development model, this conceptual framework discusses the aspects of awareness, process, reflection, and transformation, which according to Atherton (2013) and Van Oord (2013), is the path that transformative education follows.

5.1 Getting Started

5.1.1 Awareness

The importance of teaching nature's lessons in ID pedagogy not only responds to several of CIDA's systemic values for SD but also is stakeholder-driven. Addressing stakeholder and student expectations is a key consideration in curriculum development to ensure that ID programs relate to current and future demands of the profession (Karpan, 2001; Coleman, 2015). According to my research, building awareness is step one.

The resources for building biomimicry awareness are ever increasing due to the internet, and one of the best first step towards understanding the whole-systems approach to biomimicry begins with the TEDtalks videos by Janine Benyus (2005 & 2007). As co-founders of the Biomimicry Institute and Biomimicry 3.8, Benyus and Baumeister are ambassadors of the biomimicry movement. Architect, Michael Pawlyn's TEDtalks video presents his biology inspired projects and examples of nature's lessons in an architectural context (2011). These readily accessible podcasts provide an excellent introduction into the biology inspired design (BID) world of biomimicry innovation. Accessing the Biomimicry Institute's website will further this knowledge building, providing an expansive database of current research and development,

curricula and teaching tools, not to mention links to a global network of biomimics, educational partners, and innovation.

The Biomimicry Institute website is also home to the AskNature database, and the annual Biomimicry Global Student Design Challenge (BGSDC) (Biomimicry Institute, 2015). The BGSDC invites students and independent professionals, based on a themed challenge, to submit design proposals utilizing biomimicry methodology to solve human problems. Past challenges address sustainability issues to illustrate how mimicking nature could: regulate buoyancy in a ship, improve irrigation systems, or transport fruits and vegetables from field to consumer using less water and reducing damage. Not only does the Biomimicry Institute's staff orchestrate the challenge, but they also maintain an online library of submissions, providing an excellent source of inspiration and examples for linking biomimicry applications to real world problem-solving for aspiring biomimics.

5.1.2 Connect with biomimics

According to Lozano-Garcia et al (2008), an institution needs to commit to sustainability as a whole in order for it to progress. Biomimicry principles and practices have the potential to contribute to a post-secondary institution's ecological vision for its educators and students. A process to elevate biomimicry awareness in a broader context would be to:

- Become attuned to the stakeholders, and their relationships with the institution, and their research incentives or goals.
- Investigate how biomimicry fits into the institution's SD mission statements, research, development, and stakeholder goals.

- Research other faculty programs or initiatives that involve, or are planning to involve, BID to understand what interdisciplinary and cross-disciplinary opportunities exist. (As multidisciplinary programs evolve in universities, synergies and collaboration opportunities may exist for ID students with other disciplines that have not in the past.)
- Seek out methodologies and tools that address; integrating sciences into unrelated pedagogy, developing a common language and collaboration skillsets, and experiences with natural immersion.

- Seek out a biomimicry mentor(s).

More than one survey respondent noted that they were not aware of what their colleagues or other faculties were or were not teaching regarding biomimicry. Investigating whether other on-campus BID synergies exist could expose another faculty member(s) as an ally and/or mentor for a biomimicry-based initiative or cross-disciplinary collaboration. Educators that responded to my survey, who indicated they were teaching BID, recommended that connecting with others who are "doing it" is a worthwhile strategy in the integration process. The BEN website provides those connections.

5.2 Integrating Biomimicry

5.2.1 Weave biomimicry into existing SD courses

Janine Benyus (2011) believes that biomimicry is the next step once "you've committed to a sustainability [goal] like LEED [certification] or carbon footprint reduction" (n.p.). Weaving biomimicry into existing SD courses provides students with a basis for this concept.

SEQUENCING FROM SD TO BIOMIMICRY	Sustainable Design (SD)	Biology Inspired Design (BID)	Biomimicry & Regenerative Design
Concepts	- design decisions in the built environment can have a positive impact on ecological resources	- natural elements provide positive effects on human problems when integrated with environmental design	- biology holds answers for designers in solving human problems, improve ecology, and provide resources for future generations
	- focusses on building performance	- focusses on human-nature connectivity	- focusses on ecological sustainability
	- principally quantitative	- principally qualitative	- utilizes nature's lessons of *model, measure, mentor (Benyus,1997)*
Synergies	- energy conservation	- ecology conscious conservation	- construction waste reduction, biology-based innovation & human-centered design
Process	- solution-based problem solving	- hands-on and in situ experiences w/ nature	- process-based problem solving
	- human-energy conservation	- human-nature conservation	- human-nature innovation & regeneration
Collaboration Concepts	- interdisciplinary	- cross-disciplinary	- multidisciplinary
	- practice IPD collaboration	- integrate biologists	- integrate business
	- charrettes	- common language	- foster team equity
Resource Strategies	- explore eco-evaluation benchmarks and certification through LEED credential maintenance	- connect biology to design and its stakeholders - TEDtalks (J. Benyus; M. Pawlyn)	- explore biomimicry (Biomimicry Institute/AskNature) & regenerative design strategies (Cradle to Cradle/Disruptive Innovation)
	- research post-occupancy evaluation (POE)	- explore design study libraries (DSL)	- utilize AskNature & immersion in nature
Applications	- LEED Rating System	- Green Construction Code	- Living Building Challenge
	- shadow LEED teams	- experiment with advanced modeling	- engage in biomimicry design challenges
Measuring Strategies	- measure energy conservation	- assess repeatability	- evaluate deep learning skill sets & sustainability
Resource Materials:	The Designer's Atlas of Sustainability (Thorpe, 2007); Sustainability in Interior Design (Moxon, 2012)	The Way Life Works (Hoagland & Dodson, 1995); Ecological Design (Ryn & Cowan, 2007 10th ed.)	Biomimicry, Innovation Inspired by Nature (Benyus, 1997); *Cradle to Cradle* (McDonough & Braungart, *2002)*

Figure 25: Curricula development strategies, SD to Biomimicry
(by author)

Educators teaching biomimicry advise other educators, seeking an understanding of the differences between these environmental design strategies, to look

for overlapping concepts within existing curricula that link to biomimicry. Based on this thesis research, Figure 25 summarizes the key differences in seven categories relevant to understanding the how each design approach is unique, and how they would influence curriculum development in the transition from SD, to BID, and biomimicry. The chart illustrates how biology is integrated into the design process, and can influence an advanced ecological worldview. This transformation involves incremental degrees of new knowledge integrated in varying pedagogical contexts to enhance comprehension, application, reflection and assessment. As new knowledge sequences into the curriculum, the level of rigor increases to align with the critical thinking required to execute these concepts successfully.

5.2.2 Integrate systems thinking and collaboration into coursework

Course content that involves systems thinking and collaboration can provide an opportunity to introduce BID into other courses that involve collaboration and critical thinking skills. Once an educator has an understanding of the biomimicry principles, concepts, language, synergies, and resources, curriculum design is a viable next step. BID courses support CIDA Section IV requirements for complex design problems, problem-solving, and expectations for educators to strive for the advanced cognition skillsets (p.II-14). Introducing project deconstruction, C2C, and waste reduction strategies into existing design pedagogy, raises a learner's social consciousness, and an ecology-responsible worldview, concepts that speak to CIDA accreditation criteria.

Courses that involve LEED are also likely to provide opportunities for integrating BID. LEED's latest version 4 incorporates new prerequisites and credits promoting IDP, waste diversion strategies, and the triple bottom line (TBL). The TBL (planet + profit +

people eco-balance) is a theory that biomimics embrace, and provides a framework for educators to introduce biomimicry into SD assignments.

5.3 The Transition

This research has discussed a diversity of methods for integrating biomimicry into education. The integration process takes time. Time to learn, time to iterate, and time to reflect. As Chair of the Association of Registered Designers of Ontario's (ARIDO) Interior Environment Sub-committee (1993-1996), the SD initiatives the committee members developed took 5-10 years to be implemented once adopted. According to Witherell & Dubrulle (1995), the book *Walden, or Life in the woods*, published in 1854, went largely unnoticed until the 1960's when industrialization and the post-war eras contrasted that of Thoreau's human-nature experiences. Reed (2012), a practioner, acknowledges that a paradigm shift to an ecological worldview takes time.

To transition beyond LEED, Reed (2012) combines scientific and academic investigations into his project research, and proposes a phased approach in when transitioning toward problem-solving with an ecological lens. Managing the transition is as important as the integration strategy, and Reed suggests that this strategy needs to "embed developmental processes into the day-to-day work of the project in order to support the transformation of thinking necessary for communities to make any real and lasting changes to the way they relate to their living environments" (2011, p.36). The transition strategy is true for biomimicry integration as well. The results of the surveys and precedent studies suggested many transferable teaching strategies and resources for ID educators to integrate into their programs (Figure 26).

GOAL: educate the stakeholders to preserve and restore ecology in the built environment	**METHODOLOGY:** mimic nature's principles and/or processes to provide regenerative solutions to human problems
facilitate immersion in nature	field studies
	found objects study
	zoological studies
unpack the human-nature connection	Life's Principles (Biomimicry Institute)
	AskNature (Biomimicry Institute)
develop a common language	design patterning language and libraries
integrate systems thinking	Biomimicry Taxonomy (Biomimicry Institute)
	fractal patterns and parametric design
	process-driven vs. solution-driven problem-solving
	Design Lens (Biomimicry Institute)
	circular economy vs. linear economy (Ellen McArthur Foundation)
share knowledge and innovation	Biomimicry TEDtalks
	disciplinary collaboration (arch/eng/science/business)
	Biomimicry Institute Global Design Challenge
	design study libraries (DSL) of case studies
	seek out synergies within university
maximize resources	BEN (Biomimicry Educators Network)
	EDRA (Environmental Design Research Association)
	Zygote Quarterly (online BID journal, http://zqjournal.org/)
design for repeatability	modeling
	case studies
	reflection / journaling
inspire change-agents	network with ecology-minded stakeholders
	initiate BID discussions & integrate into curricula
	integrate human-centered design (awareness/consideration/action - OCADU)

Figure 26: Transferable methodologies for integrating biomimicry into ID education (by author)

The BID strategies from the various resources explored in this research study were wide ranging and did not always address sustainable solutions for the built environment. Figure 26 is a synopsis of those strategies, that educators of BID and biomimicry utilize to meet the biomimicry education goals, that are most adaptable to ID education. Based on my research of course models, there are many established methods and tools for the advancement of biomimicry in Canadian ID education. ID educators are clearly interested in biomimicry, however they require a roadmap to integrate it into their curricula that is credible, repeatable, and conscientious of their time constraints when building and incorporating new knowledge into their programs.

5.3.1 Utilize immersion in nature as a classroom for biomimicry education

Consider opportunities to organize lectures, charrettes, studios, and outdoor labs in nature-based settings. Immersion in nature provides an environment for student inspiration, reflection, and regeneration. A research study *Creativity in the Wild: Improving Creative Reasoning through Immersion in Natural Settings* (Atchley, Strayer & Atchely, 2013), found that tuning-out technology and tuning-in nature expands creative problem-solving. Connecting nature to design *in situ* is the preferred methodology by the educators interviewed when introducing biomimicry into non-science based curricula. One of the interviewees surveyed observed through *in situ* explorations that “when students fall in love with nature they are inspired to protect it”.

5.3.2 Participate in biomimicry student competitions and challenges

In my survey, 4/5 U.S. educators responded that applying biomimicry is challenging for students. And although the majority of students from both countries reacted positively to biomimicry, one respondent noted that any negative feedback

stemmed from students not understanding how nature can be applied to design. Student design competitions, or challenges, have become popular vehicles in biomimicry knowledge building, providing opportunities to practice biomimicry applications on collaborative teams, connecting biology in real-world settings.

The Biomimicry Institute, in partnership with the Ray C. Anderson Foundation, first introduced the Biomimicry Global Student Design Challenge (BGSDC) in 2011 to expose the global university student community to biomimicry not taught through their institutions (Biomimicry Institute, 2105). BGSDC focuses on sustainability challenges pertaining to energy and water efficiency, transportation, and food generation to date. Today the competition is open to students and SD professionals, in order to expand the number of entries, and interdisciplinary team participants, and reviewed by a global panel of eighteen judges. This judging panel combines academics, design and engineering practitioners, artists, agriculturists, business consultants and authors, all with expertise involving SD, BID and biomimicry. Entries are evaluated on how well the proposals define and understand the challenge, their ecological benefits and judged on:

- biomimicry process
- creativity
- feasibility
- social and environmental benefits
- communication and presentation
- team

According to the Biomimicry Institute website, between 2011 and 2014, there have been 2,500 participants from 51 countries, 6 continents resulting in 3 products and 1 patent

resulting from these design challenges. Canadian institutions have been among the finalists, and student teams from McGill University and the University of Calgary delivered winning entries in 2014 and 2015 respectively (Biomimicry Institute, 2015).

The Ellen MacArthur Foundation initiated the Disruptive Innovation Festival Biomimicry Design Challenge in 2014, again won by the University of Calgary student team. According to Hassanali (2014), the competition focussed on the use of biomimicry methodology to advance the food supply chain respective to production and distribution cycles that are environmentally responsible. The winners received the most votes by the public attending the five-day Disruptive Innovation Festival.

5.3.3 Collaborate with other stakeholders to explore, debate, and develop multidisciplinary and biomimicry concepts

Fifty percent of the educators in my interviews believe that the greater the multidisciplinary 'integration factor' the more effective the delivery of a course, and the integration of biomimicry could be within their institutions. For example, OCADU's Faculty of Design course 'Think Tank 1: Awareness' course, focussing on 'Design and Humanity, was designed to complement curricula across six disciplines. A think tank collaboration strategy was also utilized by CIDA to facilitate discussions regarding the future of ID education, which centered on strategies to elevate the profession's "influence and value" (Coleman, p.ix, 2015). This collective formed a group of 30 participants from a cross-section of ID educators, practitioners, and allied disciplines.

In professional practice, a think tank model is the core of RVTR's studio environment (RVTR, 2015). RVTR, a Canadian self-described design-research firm, focuses on emerging ecologies and experiments with the integration of biological and end-of-loop considerate applications in the built environment. According to RVTR, the

firm believes that every team member has an important and equitable role in the project development and execution process. A think tank collaboration of faculties within an institution could become a catalyst for the development of a multidisciplinary biomimicry MOOC open to all learners. There is not one action-plan to introduce biomimicry into curricula but if educators utilize a think-tank model, solutions that work best for their program or campus culture are realizable.

5.3.4 Consider biomimicry strategies for problem-solving

CIDA offers several opportunities to include biomimicry in its sustainable design mandate. As discussed in this thesis, biomimicry contributes to an interior designers BOK and may satisfy CIDA's criteria for interior designers involving; human-centered design; collaboration; global view; environmental systems; design research and problem-solving; interaction with multiple disciplines; as well as human health and welfare. These are all-important elements in the advancement of ID education and practice, according to the Future Vision think tank outcomes.

McDonough & Braungart (2005) spell out five guiding principles for industry and practitioners in the transformation process:

- Signal your intention (commit to the new paradigm)
- Restore (strive for good health)
- Be ready to innovate further
- Understand and prepare for the learning curve (change can be difficult)
- Exert intergenerational responsibility (the earth belongs to the living)

According to McDonough, these principles evolved from a broad base of architectural experiences and are representative of the rigor this new knowledge demands.

5.3.5 Rethink learning objectives, strategies for evaluating student progress, and developing course curricula

Repeatability, or the ability to repeat a process with the same or similar outcome, is an inherent characteristic employed by nature. As the seasons change and nature's species migrate to warmer climates, hibernate or die, they ingeniously return and are reborn in the spring. This regenerative life cycle is one that repeats for billions of years, and provides valuable lessons for humans and their inventions. Evolution adopts what works from the previous generation, improves on it, and recreates a new model for pilot testing. Repeatability is one aspect of nature's lessons, and is mandatory for biology inspired designers to articulate in the evolution of their creations. Biomimicry educators have found reflective journals essential in evaluating learner comprehension and deep-learning abilities while exposing underlying appreciation for nature, as well as assessing the success of the program of study (Wallack & Webb, 2007; Warburton, 2003). Design iterations and journaling provide evidence of the learning process, are valuable assessment tools, and essential for repetition (Karpan, 2001). Evidence-based design relies on repeatability, which provides critical feedback for the advancement of designers and their BOK.

Angne (2012) explored the concept of repeatability by utilizing a cyclical strategy to integrate biomimicry into her interior design course. As described in Chapter 4, Section 2.2, by repeating biomimic principles and processes on a regular rhythm through the 11-week course, Angne could monitor the success of the pilot course curriculum. This systematic reintroduction of the biomimicry concepts allowed the students a period of reflection between cycles. She, as well, could stay attuned to the students' cognitive progress of the biomimicry concepts, reinforce them through

repetition, monitor the level of deep learning as the course advanced, and measure the outcomes on an ongoing basis rather than only at the course conclusion. This sequenced teaching strategy and the resulting documentation provided valuable insights and repeatability of the course curriculum for subsequent semesters.

The sequencing of new information is an important element in curriculum development (Karpan, 2001). In the paper A Biomimicry Primer, Benyus (2011) describes three levels of biomimicry integration. Figure 27 illustrates the three progressive levels to sequence in biomimicry methodologies, with examples of how each level relates to the same species based on Benyus' strategy.

Biomimicry level	Application principle	Example in nature: owl feather
1 - Natural Form	Resembles a shape that provides a desired function	Mimic the hooks and barbules of an owl's feathers to create a fabric that opens anywhere along its edges
2 - Natural Process	How an organism functions	Owl feathers naturally self-assemble at body temperature without toxins or high pressures
3 - Natural Eco-system	Considers how each part of a design impacts the environment as a whole	An owl feather is nested with the bird, which is part of the forest, which is part of a sustaining eco-system

Figure 27: Three levels of biomimicry
(by author adapted from A Biomimicry Primer, Benyus, 2011)

According to my research, educators could integrate biomimicry into existing interdisciplinary or SD courses, or teach it as a stand-alone course. Fifty percent of the educator interviewees believed that integrating biomimicry into as many courses as possible was more effective in reinforcing and practicing the concepts from a more holistic perspective. The remaining educators were proponents of a stand-alone course that would allow students a more focussed venue to better comprehend, apply, and

reflect on the complexities of biomimicry in a collaborative setting. Benyus (2011) states, “For designers, architects, engineers, and innovators of all stripes, the answer to the question “What would nature do here?” is a revelation. There’s not one new idea, but millions …” (n.p.).

5.4 Building Critical Mass

5.4.1 Become a Biomimicry Fellow

The Biomimicry Institute’s BEN and affiliations provide resources for an educator and an institution to become a member. For the educator, the 1-week biomimicry immersion workshop is an ideal vehicle for deepening the appreciation for nature’s genius, while connecting with other global educators and biomimics. With two faculty members as Biomimicry Education Fellows, an institution could become an Affiliate member, aligned with seven other institutions such as OCADU in Canada, ASU, MCAD, and four other U.S. universities (Biomimicry Institute, 2015).

5.4.2 Develop partnerships to share integration strategies, synergies, and ways to broaden the stakeholder base

Crossing disciplines within an institution is a perceived challenge according to participants in my survey. The educator interviewees reiterated similar comments. Educational institutions are seemingly poised to deliver new topics that will benefit students in their careers, however creating a sustainable world falls on the shoulders of many stakeholders, according to Orr (1992). CBID continues to cross disciplines, and understanding BID as a multidisciplinary design process adds an ever-expanding network of stakeholders to their center’s research base including expertise from biology and applied sciences, business, design, architecture, engineering, and technology. As well, CBID’s stakeholder network includes community, government and industry

partners. Collaborating with stakeholders that include associations, organizations, and community, exposes students to industry and volunteer opportunities beyond campus parameters. These partnerships provide a valuable resource for institutions, their faculties and students, for guest lecturing, student project critiques, work-sharing and future career opportunities.

Construction Resource Initiatives Council (CRIC, 2013) believes partnerships are the cornerstone in the success of their initiatives and progress. Their organization models best practices and provides a foundation to accomplish this through effective communication, awareness and advocacy, integration and education, commitment to tools and support, sustainable development, as well as research and technology for zero waste. Initiatives like Mission 2030 engage public and private partnerships, and challenge design professionals that are responsible for the built environment. Interior designers are poised to play a bigger role on these sustainable initiatives, and multidisciplinary design firms like HOK have embraced biomimicry and integrated it into their corporate culture (King, 2012; Verbeek, 2011).

The Center for the Built Environment (CBE) at UC Berkeley University has cultivated an extensive list of 'sustaining members', including twelve high profile manufacturers and organizations, and twenty-five engineering and construction companies (CBE, n.d.). The CBID at Georgia Tech involves more than twelve different colleges and schools, plus prominent professionals in advisory capacities (CBID, n.d.). The Schulich School of Engineering, University of Calgary, believes that collaborating with community and industry is important to guide their curriculum development, propose and present research opportunities, not to mention providing mentoring and

employment resources for their students (Schulich School of Engineering, n.d.). These institutions are just a sampling of how biomimic partnerships can change how students, practitioners, and the community views progressive education.

5.4.3 Explore BID research in related industries and opportunities to participate

Interior designers must take ever-increasing responsibility for the methods and materials they choose, and consider the life cycle impact those choices make on the environment. Manufacturers, aware of these challenges, now have various mechanisms for certifying their products to meet these environmental standards. Some companies, more than others, are taking the lead toward self-directed accountability such as Interface, Teknion, Herman Miller, Steelcase, and Wilsonart, most of whom are members of Sustainable Brands (SB). SB's global members share common regenerative goals for waste diversion, renewable energy, and closed-loop manufacturing. Interface and Steelcase share close connections with Biomimicry 3.8 and have recognized the value of nature's lessons in their manufacturing loops. Sharklet and Steelcase have engaged in a research partnership that is experimenting with Sharklet's anti-bacterial films and Steelcase's injection molding technologies for their furniture (Mangham, 2013). These firms are models of BID innovation in manufacturing that directly contributes to the ID industry. Interior designers and their clients benefit from these innovations, and with evidence-based research, interior designers will know that their biomimicry knowledge and practices will be valued.

5.4.4 Become an agent for change

According to interview participants in this thesis study, educators are the champions of new topics in their programs, and best poised to shift their curricula

towards ecology-positive pedagogy. Over the course of this thesis research, models for BID course content has become more evident in Canadian post-secondary institutions. Design teams from OCADU, The University of Calgary, and McGill University are successfully participating in global student design challenges. Professor Eggermont, a senior instructor and associate dean of student affairs at the Schulich School of Engineering at the University of Calgary, was impressed that such an accomplishment could be attained when the biomimicry student club, named 'Enova', was only two months formed (Hassanali, 2014). Eggermont, an Arts major, and the founding co-editor, publisher and designer of the e-journal Zygote Quarterly. Zygote Quarterly is a web-platform to connect bio-inspired multi-disciplinary professionals with community, illustrating biomimicry innovation when design meets science. The sharing of bio-design strategies through networking, mentoring and design challenges all contribute to the advancement of the biomimicry revolution, and awareness for the ID community.

For industry, the Sustainable Brands' (SB) 'Activation Hub' is their portal to facilitate industry partners to share solutions and mentor new members. One of SB's and the Biomimicry Institute's best known industry partners is Interface, the U.S. carpet tile manufacturer. Ray Anderson the founder of Interface, inspired by Paul Hawken's book *The Ecology of Commerce* (1993), adopted an environmental worldview that influenced his company's entire business model to revaluate how carpet manufacturing was affecting nature, and how nature could transform carpet manufacturing (Interface, 2009). The Interface model challenged the industry to do the same. Through Anderson's epiphany, the name Interface, is not only the name of the world's leading

maker of carpet tile today but evidence of how one man can affect the present and future ecological health of our planet.

Ray Anderson was, and Interface is the face of carpet tile innovation today. Putting a ‘face’ and a ‘name’ to biomimicry initiatives contributes to building awareness, engages participants, creates momentum, and makes it visible to stakeholders. Based on the examples of the biomimic pioneers presented in this research, ID educators, once empowered with advanced ecological knowledge and tools will be the models for change in their programs and institutions.

6.0 Final Summary, Recommendations and Conclusions

Biomimicry is a biology inspired design (BID) strategy that mimics ecological principles, processes and systems in order to solve human problems. Design practitioners, manufacturers, and educators in the U.S. have recognized biomimicry as a valuable problem-solving methodology that minimizes material-impact on the environment and promotes resource regeneration. As a multidisciplinary practice, biomimicry provides expanded opportunities for interior designers to collaborate with diverse disciplines and stakeholders that may not have existed before.

Based on the premise that biomimicry strategies are integrating into U.S. ID programs, the focus of this research was to learn if and how Canadian programs compare in this movement. The thesis study explored four primary BID research themes:

- how biomimicry can advance ecological responsibility in an ID context
- why biomimicry should be considered by ID educators, and what criteria must be considered for curricula development
- how a complex biology-based topic can dovetail with ID education
- what are the lessons learned and next steps to advancing biomimicry in Canadian ID programs

Through a mixed-method research design, the study produced a foundation of information to inform my thesis development. Firstly, there was an abundance of online research studies and literature on biomimicry and BID, which expanded almost daily. Secondly, by surveying North American post-secondary educators in design-related disciplines and compiling a precedent study of BID and biomimicry courses, a cross-

section of integration strategies for Canadian educators informed the development of a conceptual framework. Through this research study, the extent to which biomimicry has infiltrated U.S. and Canadian ID programs surveyed is understood, but not conclusive. The survey participant responses uncovered that biomimicry has penetrated 13/22 of the post-secondary ID programs in North America. The U.S. remains comparatively further ahead of Canadian programs in biomimicry experience since Angne's 2012 study. However, Canadian responses provided statistical data indicating that biomimicry has established a foothold in Canadian education. As compared to my review of literature, very few Canadian questionnaire respondents were unfamiliar with biomimicry.

This study also explored factors important to ID curriculum development and CIDA criteria. Biomimicry speaks to many of the standards that make up the framework of ID education, including global perspectives for design in ecological contexts, design process, collaboration, communication, finish materials, environmental systems, building systems and interior construction, and assessment and accountability. Introducing BID relies on learners mastering the ability to: communicate with a widening cross-section of disciplines, utilize biological concepts, execute process oriented problem-solving strategies, and think critically about, reflect upon, and document the process. Biomimicry is multilayered, involving systems thinking, and demands the rigor required by CIDA in its efforts to advance the profession of ID. Interior designers, equipped with BID knowledge and skillsets, have an elevated capacity to provide healthier solutions for their clients and the planet.

Integrative design teams, mimic nature's interdependencies, look beyond their own disciplines for problem-solving strategies. Cross-disciplinary collaboration delivers both benefits and challenges. The survey revealed that biomimicry is a well-received topic by students although some educators reported application challenges when students are trying to grasp biological concepts. Developing a common language is essential when interweaving diverse disciplines, with their domain-specific vernacular and skillsets. The research confirmed that when design problem-solving filters through a biological lens, it results in an ecology-positive outcome. The AskNature online database of biological strategies provided by the Biomimicry Institute is an accessible and democratic tool for all disciplines, delivering examples of how nature can influence design while respecting nature.

From the lessons learned various integration strategies and teaching techniques for Canadian ID educators were realized, both high- and low-tech. Immersion in nature, although currently not a highly utilized teaching strategy based on the questionnaire results, was a popular strategy for introducing students to biomimicry by 3 out of 4 interviewees. When students experienced nature's lessons during *in situ* reflections on human-nature connectivity was enhanced. Spending time in nature provides learners with hands-on opportunities to experience how the natural world approaches design patterning, interactions among species, and processes that provide for material regeneration. Academics also stressed the importance of reflection and repeatability in BID strategies, but observed the effect timing, and time (or lack of) would have on integration process. By weaving Life's Principles into one course, educators observed

that students could transfer those concepts into other courses as well as into their own worldviews.

To continue this thesis work, further research could focus on the outcomes of biomimicry application from ID learner and practitioner perspectives. Research into these areas would assist educators in better understanding the effectiveness of their teaching strategies and tools, as well as the sequence of integrating biomimicry into their ID curricula. A think-tank model could potentially be an effective first step for cross-faculty educators and stakeholders to brainstorm and collaborate in the shared research and development of a biomimicry resource centre, lab, or course. More research that explores strategies to facilitate crossing disciplines would benefit ID educators and students, providing them with new collaboration opportunities with a wider cross-section of ecology-minded stakeholders.

ID educators believe that through multidisciplinary experiences, the communication and collaboration skillsets their students learn on biomimicry teams will empower them to manage real-world challenges. As illustrated in nature, collaborating with a wider net of stakeholders is fundamental to advancements in biomimicry application strategies and innovation. As stakeholder nets widen, through ecology-based public-spirited collaboration, new career opportunities for interior designers may occur in research, consulting, business and community sectors that have not existed in the past.

Educating interior designers to look to organisms for design inspiration is a unique problem-solving strategy for students and educators alike. To weave biomimicry concepts into ID programs, educators need to employ curricula strategies that deepen

collaboration skillsets, involve multiple disciplines in the topic delivery and on student project teams (involving biologists whenever possible), and provide mechanisms for utilizing nature's strategies for design innovation. Although biomimicry offers ID educators with options to weave new knowledge into their programs, there is not a 'one size fits all' implementation strategy. Introducing biomimicry into ID courses using a systematic approach allows time for reflection, resulting in more positive student and course development outcomes. Integrating biomimicry into ID curricula is challenging. My research revealed that when educators take ownership of their professional development and build their awareness of biomimicry, they acquire the skill sets to advance ecological strategies in their ID programs. Awareness is the first step towards biomimicry integration in Canadian ID education.

Canadian educators need to make room in their programs for new topics that advance the ID student's problem-solving abilities and collaboration skill sets that will contribute to their employability. This study observed that biomimicry not only expands the interior designers' BOK but deepens their understanding of the ecological impact design has, present and future. The more that biomimicry is recognized as a valuable multifaceted design methodology, the more empowered interior designers will be, and more valued the profession will become, as the curators for healthy indoor environments. Through the evidence-based research biomimicry innovation provides, Canadian ID educators have access to the teaching tools and implementation strategies required to integrate biomimicry into their curricula. This thesis concludes that if education is the bridge between SD and biomimicry, Canadian ID educators are the agents for change today and their students the ecological-design leaders of tomorrow.

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APPENDIX A

Glossary of Terms

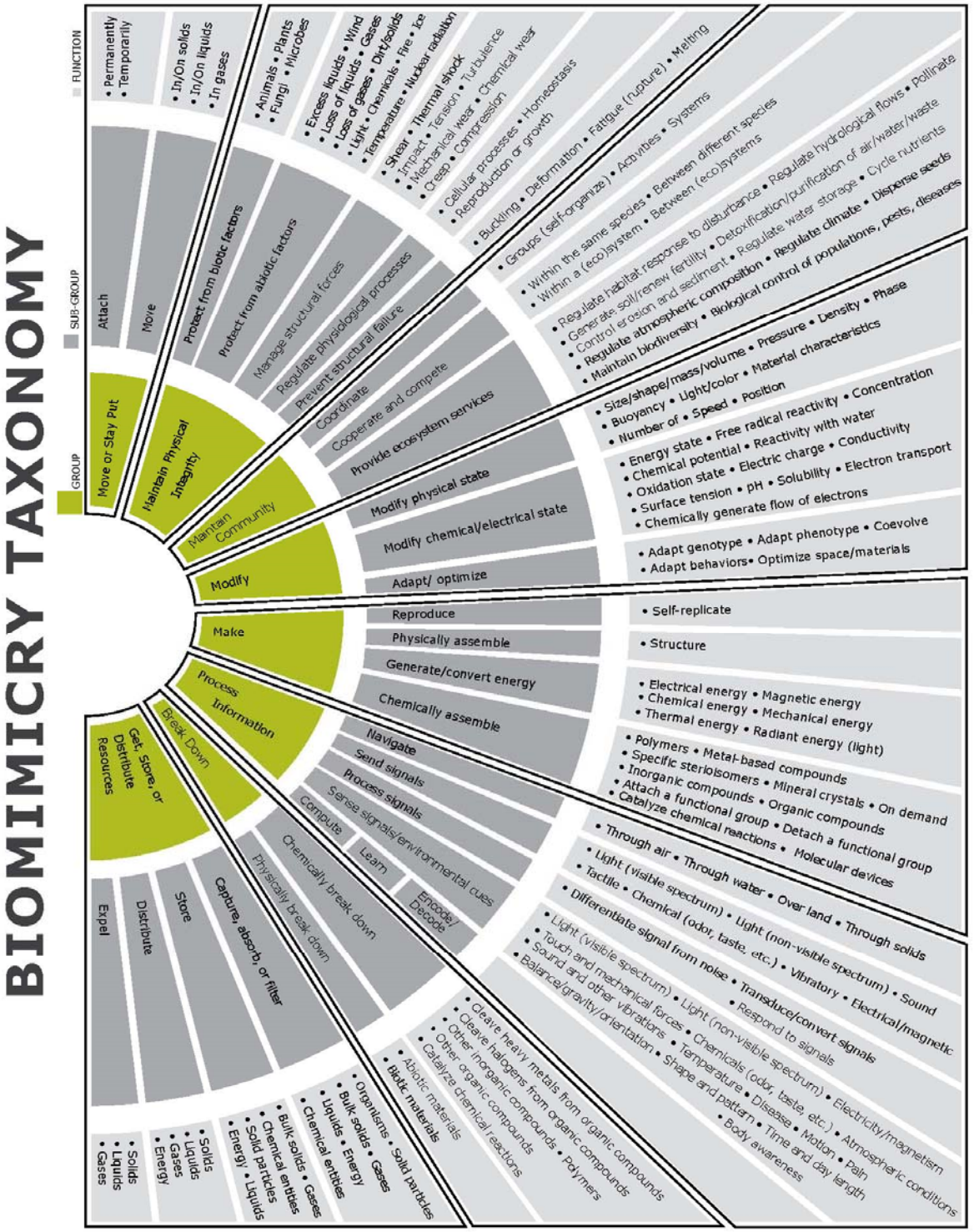
Term	In context of the built environment
biologically inspired design (BID)	the integration of biological principles, processes and practices into design methodology (see biomimetics, biomimicry, and biophilia)
biome	"a major ecological region such as tundra, tropical forest, or grassland, that, when considered on a global scale, may contain a large range of different ecoregions or bioregions around the world" (Thorpe, 2007, p.47)
biomimetic	"the study of the formation, structure, or function of biologically produced substances and materials, and biological mechanisms and processes especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones" (Meriam-Webster.com, 2013)
biomimicry bio = biology mimicry = to mimic something	involves taking inspiration from natural processes and structures (Thorpe, 2007, p.46), and how nature acts as opposed to how nature looks (Benyus, 1997)
biophilia	"emphasizes the necessity of maintaining, enhancing and restoring the beneficial experience of nature in the built environment" integrates natural elements, themes and patterns into conventional building elements to provide an emotional connection to nature (Kellert & Heerwagen, 2008, p.vii)
cradle to cradle (C2C)	a concept to describe a closed-loop lifecycle whereas "waste = food" (Stieg, 2006, p.xi) and the title of a book written by architect W. McDonough and chemist M. Braungart in 2002 emphasizing the necessity to design objects that will become nourishment at the end of their initial intended use
cross-disciplinary	refers to the blending of principles, processes, and practices that cross-over disciplines
fractal	repetitive patterning - could be mathematical or intuitive such as found in nature
input / output	input = consumption / output = waste (Stieg, 2006, p. viii)

Term	In context of the built environment
interdisciplinary	the links and the transfer of knowledge, methods, concepts, and models from one discipline to another (cited in Armstrong, Connell, Musgrove & Remington-Doucette, 2013)
mimesis	"requires the imitator to embody that which is being imitated" and have "empathy for the object of the examination" but must be balanced with the symptoms of the unsustainability (Hutchins, n.p., accessed Jan.22.14)
multidisciplinary	research that studies a topic not only in one discipline but in several at the same time (cited in Armstrong et all, 2013)
pattern literacy	"a coherent organization of information, and the relationships an connection between discrete pieces of information and different types of information" (Cole, 2012, p.3)
regenerative	“approaches that support the co-evolution of human and natural systems in a partnered relationship” (Cole, 2012, p.1)"challenges the orthodoxy of current green building practice and the design tools that support. Building environmental assessment methods were initiated by and have evolved within the domain of mainstream building practice. They have been premised on incremental advances rather than more fundamental challenging of practice" (Cole, 2012, p.2) "doing less harm" (Cole,2012, p.3)
solution-driven	based is a traditional problem-solving methodology where the emphasis is the deliverable versus problem-driven where the emphasis is on the process (which is the preferred methodology for biomimicry) (Sosa et al., 2010)
STEM science + technology + engineering + mathematics	a teaching methodology utilized in 2005 at The Georgia institute of Technology that originated as a collaboration between biologists and engineers, however broadened over time to include other disciplines to enrich the interdisciplinary idea exchange (Helms, Vattam, Goel, Yen & Weissburg cited by Cohen, 2012)
systems-thinking	to apply a pragmatic methodology to the research and application of bio-design (which results in an evidence-based solution)

Term	In context of the built environment
taxonomy	"the process or system of describing the way in which different living things are related by putting them in groups" (Merriam-Webster.com, 2014) employed by the Biomimicry 3.8 institute as a tool to understand bio-design principles and applications
transdisciplinary	research that involves what is between the disciplines, across the disciplines, and beyond the disciplines (cited in Armstrong et all, 2013)
transformative change	"a new operating system that routinely delivers good results for people and planet at home and around the world" (Cole, 2012, p.4)
triple bottom line	Planet (environmentally cognizant) Profit (economy positive) People (human-centered)
TRIZ	a catalogue style problem-solving tool to understand examples of other techniques in nature (Faludi, 2005)

APPENDIX B

Biomimicry Taxonomy Chart



APPENDIX C

Precedent Study: Biology Inspired Design Curricula

Course	Student Make-up	Structure	Strategies & Methodologies
2005 - present **Georgia Institute of Technology** United States 15 week course (Helms et al., 2009 Yen et al., 2012)	STEM Student Teams: 6 biology 7 mechanical engineering 25 biochemical engineering 3 industrial designers 4 from other disciplines (41/45 students have taken at least one design course previously)	- 2 projects - final report (15-20 pages) - an oral presentation - 6 step problem-driven approach: 1. Problem definition (designers were asked to find or invent a problem and then define their problem as a function based on functional decomposition and functional optimization) 2. Rename the problem (in a biological context) 3. Biological solution search 4. Define the biological solution 5. Principle extraction 6. Principle application	- faculty lectures (across 6 faculties) - guest lecturers (prominent experts) - found object exercises - journaling - case studies - TRIZ - SAPPHIRE (a tool that provides descriptions and language of structures, behaviours and functions of biological and engineering designs)
2011 - present **School of Design & Visual Arts** Washington University United States 1 semester course (Freixas, 2011)	Student teams were made up of: - biology - engineering - architecture - other	Collaborative studio: Session 1: - lecture on biomimicry in architecture - video by Janine Benyus - students self-assemble interdisciplinary teams (mixing grad and undergrad students) - Assignment 1; teams are assigned 3 organisms to consider for exploration to consider for exploration and based on an inquiry of 3 questions teams must prepare a preliminary presentation in a seminar using pin-ups and reviews in the studio Sessions 2 & 3: - Pin-up Assignment 1 - Assignment 2; teams receive feedback from professor, teaching assistant and peers and narrow down their organism to one selection and asked to consider what is unique to the organism at a micro and macro scale, what is surface vs. structure, what is muscle vs. bone, and what is rigid vs. flexible? Session 4: - Guest lecturer - review the deeper investigations; critiques the graphic legibility of the ideas - build models using bristol board and other connection material Sessions 5 & 6: - Pin-up Assignment 2 - teams attend lectures by various professors on kinetics, architecture, digital modeling and biomimicry Session 7: - Review Assignment 2 - Guest lecturer critiques the clarity between components and connections in the models Sessions 8 & 9: - Pin-up Assignment 3 - Review Assignment 4 Sessions 11, 12 & 13: Pin-up Assignment 4 Session 14: Review of final deliverable - through the use of coherent documentation of the design process and comprehensive understanding of the performative aspect of the organism, representation methods and scales including diagrams, technical drawings, study models, renderings, animations, and a full scale 1:1 model	Students investigate the relationships between nature and the built environment through a systematic dissection and documentation investigation of particular organism's natural process in terms of its mechanical performance on a macro and micro scale through the various methodologies: - faculty lectures - guest lecturers - pin-ups - peer review - workshops (labs) - independent exploration of natural models - Biomimicry Life's Principles & lens - physical and digital models

Course	Student Make-up	Structure	Strategies & Methodologies
2011 - present **Biomimicry: An Interior Design Teaching Tool** (a pilot integrating biomimicry into an interior design course) Art Institute of Inland-Empire of California United States 11-week course (Angne, 2012)	Interior Design students	11 week course design considering of reiterative deadlines at Week 4, Week 7, and Week 11: - weekly field studies and sketching - weekly modeling exercises - studio project 1. Weekly 'out of doors' exploration for sketching and journaling allowed student to learn how to value and appreciate nature, as well as observe patterning and how nature functions, and reflect on their observations. 2. Weekly modeling exercises were used to translate biological concepts into design studio projects on both micro and macro levels. 3. At the end of each cycle the Life's Principles Checklist was used by the students to monitor and evaluate their ideas against sustainability targets.	This course was conceived on the premise "how would nature do it?" It evolved into a 11 week Design Spiral inspired course and the platform for measuring project development to discover, abstract, emulate, evaluate, and design based on nature's processes. The course structure repeated encounters with the same material, therefore covering the principles multiple times at various stages throughout the process allowing the students to think critically about their solutions. Resources and techniques: - Biomimicry 3.8 database, AskNature - Life's Principles Checklist - TED Talks - Reading: The Way Life Works (Hoagland & Dodson, 1995) - Case studies - Field study - Journaling - Modeling
2013 **Introductory course in sustainability** United States (Remington-Doucette et al., 2013)	- unspecified		Transdisciplinarity builds on and goes beyond interdisciplinsary by integrating a wider community of stakeholders outside of the university in real-world scenarios. - Systems Thinking: students were evaluated based on their ability to identify and critically reflect on the values pertinent to a specific sustainability challenge - Normative Thinking: based on projecting a future ideal pertaining to the way the world should target sustainably - Strategic Competence: engage with stakeholders to realize their respective values, preference and beliefs; the ability to collectively design and implement interventions, transitions, and transformative strategies to steer ideas on sustainability; and recognize the hurdles, real or perceived - Case studies

Course	Student Make-up	Structure	Strategies & Methodologies
Biomimicry Educators Network - University Education Program Biomimicry Institute 12-class online course curriculum	- open to all learners	Outline: 1. Introduction to Biomimicry and Systems 1.1 Introduction to One Another and Biomimicry 1.2 What is Biomimicry? 1.3 What is a System? 1.4 A Biomimicry Approach to Change 2. Innovation Inspired By Nature 2.1 A Focus on Shelters 2.2 Completing Shelters 2.3 Example Field Trip: A Focus on Food 2.4 A Focus on Healing Ourselves 2.5 Example Field Trip: A Focus on Cleansing and Energy 2.6 A Focus on Storing Knowledge 2.7 A Focus on Conducting Business 3. Being a Biomimic: Designing and Acting to Change Systems 3.1 Creating with Nature and Being a Biomimic	Biomimicry 3.8 states that biomimicry is a rigorous science and methodology, and their University Education Program was developed to support educators and their students to work collaboratively and consciously to bring innovative and sustainable designs to fruition using biomimicry principles. The Biomimicry Educators' Network provides a forum for biomimicry educators to exchange ideas, share curricula, and explore how best to integrate biomimicry into their existing courses. 1. Become knowledgeable and enthusiastic about biomimicry. 2. Get outside and strengthen relationships with the local environment. 3. Learn to better recognize, observe, and think creatively about processes and systems in nature. 4. Shift to see nature not as something to exploit but as a teacher and model. 5. Collaborate with nature to devise and apply practical solutions to current challenges. Readings: - Biomimicry: Innovation Inspired by Nature (Benyus, 1997) - Dancing with Systems (Meadows, 2004) - Additional sort articles, resources, and websites as assigned Tools: (visuals and handouts) - Learning from Nature: A course in Biomimicry - Slides on Biomimicry - Biomimicry Taxonomy - Course Outline for Students - Slides on Systems Thinking - Living Machine Handout - Case Studies - various webinars

Course	Student Make-up	Structure	Strategies & Methodologies
Biomimicry 1: Points of Departure **GDES 3B18** Environmental Design Program Faculty of Design Ontario College of Art and Design University (OCADU) Toronto, Ontario Canada 1 semester studio	- open to all undergraduate students	1. Promotes a better understanding of how naturally occurring processes may be used as design inspiration for the development of forms, structure, systems and interactions. 2. Students will practice the logic of nature by the minimizing of material and energy consumption or in their self-sustaining and self-renewing qualities A practical overview of: - Biomimicry principles and current key issues - Concepts of using ideas from nature and transferring them to other domains such as structural design, new materials technology, sustainability and engineering	Key philosophical and thematic curricular strategies that provide links between the two programs: 1. The **"Design and Humanity" philosophy** is reinforced through a spine of design process courses: **Think Tank 1**: Awareness **Think Tank 2**: Consideration **Think Tank 3**: Action The courses are open to Design students from all disciplines, and encourage research, discussion, collaboration, strategy development and material solutions. 2. A second strategic curricular element, called Expansion Studios allow students to pursue breadth and depth of knowledge in all programs through a variety of selective course offerings beginning in the third year, that expand their knowledge into other program areas, or take courses in one area for more focused study. As these expansion studios are interdisciplinary in nature, students from a number of (appropriate) disciplines will have access to them, again providing a multi-disciplinary experience that broadens and deepens their understanding of their own and other disciplines. 3. A third strategic curricular offering is that of program Minors. Throughout the university, in the Faculties of Art, Design, Liberal Arts & Sciences, and School of Interdisciplinary Studies, optional Minor programs have been developed. Students may declare a Minor in Furniture, Photography, Material Art & Design or Social Sciences to mention a few, and complete the required additional courses for that specific Minor. 4. A fourth organization element in the design curriculum is the identification of Core Studio Practice in the form of core studios. These studios form the essential spine of every program.
Biomimicry 2: Application **GDES 3B28** OCADU 1 semester studio	- students must have prerequisite course Biomimicry 1	1. Provides students with opportunities to apply biomimetic principles learned in GDES 3B28. 2. Allows students to deepen their understanding of self-sustaining, self-renewing, and intelligent project solutions Course Activities: - Application of biomimetic principles to the design of innovative products and structures or systems - Research and analyze natural materials, structures or processes - Utilization of principles inspired from nature as a basis for design development	

APPENDIX D

Questionnaire: Survey Questions and Responses

UNIVERSITY OF MANITOBA | Faculty of Architecture

Department of Interior Design
Winnipeg, Manitoba, Canada
Telephone (204) 474-9386
Fax (204) 474-7533

THESIS RESEARCH QUESTIONNAIRE

Beyond LEED®:
Constructing a bridge to biomimicry for Canadian interior design educators

My name is Karen Cash, and I am a graduate student researcher conducting a mixed-method inquiry as part of the thesis requirements for a Masters of Interior Design degree at the University of Manitoba. I invite your participation in this study by responding to 25 questions of which should only take a few minutes to complete. **I would greatly appreciate your response to this questionnaire no later than May 15th, 2014.**

Biomimicry, according to Janine Benyus co-founder of Biomimicry 3.8, is where a nature-based lens is used to solve human problems. It differs from biophilia which resembles the way nature '*looks*' by employing the principles, practices, and processes in the way nature '*acts*'. One example of biomimicry being applied in the built environment is where termite mounds are studied for their self-cooling properties and applied to the design of an office complex's air conditioning system. Another example is the mimicking of the self-cleaning properties of the lotus leaf as a fabric finish to repel water and stains. For the purpose of this study the term *bio-design* is used to describe the integration of biology in a design context.

The purpose of this research is to:
- Learn the extent to which North American post-secondary institutions teaching sustainable design utilize bio-design as a strategy, and determine if there are differences between Canadian and American programs in this regard
- Investigate whether bio-design and interdisciplinary thinking is being integrated into interior design pedagogy, and confirm biomimicry as a sustainable design strategy being taught
- Understand the potential challenges in teaching and learning these concepts for the eventual development of a bio-design tool for educators

I invite you to participate in my research study by taking the following online survey. It is strictly voluntary and completing this survey will confirm that you have understood the information regarding participation and agree to be a respondent. In no way does this waive your legal rights nor release the researcher or involved institution from their legal and professional responsibilities. There is no known risk regarding this research inquiry. You are free to withdraw from the study at any time, without prejudice or consequence. Should you choose to provide your contact information at the end of this questionnaire those contact details will be kept in confidence, used for the sole purpose of this study, and will in no way be published in the thesis paper without specific approval. Only myself and the other member of the University

of Manitoba research team will have access to the raw data, that being my thesis advisor, Dr. S. Mallory-Hill, who can be contacted at S_Mallory-Hill@umanitoba.ca or (204) 474-7441.

This questionnaire has been approved by the University of Manitoba Joint-Faculty Research Ethics Board. If you have any concerns or complaints about this research project you may contact the above-named person or the Human Ethics Coordinator (HEC) at (204) 474-7122 or Margaret.Bowman@umanitoba.ca. Please feel free to print this consent form for your reference and records.

The results of this questionnaire will form part of my research inquiry, and once completed, will be published on Mspace at the University of Manitoba thesis and dissertation library website. Should you wish to receive a copy of the finished study you may contact me directly at umcashk@myumanitoba.ca.

Thank you for your participation in my research!

QUESTIONNAIRE: Survey Questions	U.S. Responses (n=8)		CAN Responses (n=16)	
Answer Options	**Response %**	**Response Count**	**Response %**	**Response Count**
1 - In which country is your college/university located?				
Canada		0	100.0%	16
United States	100.0%	8		0
answered question		**8**		**16**
2 - Does your program integrate sustainable design strategies into the curriculum?				
No		0	13.33%	2
Yes	100.0%	7	66.67%	10
We plan to in the future		0	6.67%	1
We have in the past but not at this time (please		0	13.33%	2
answered question		**7**		**15**
skipped question		1		1
Respondent Comments			We have an Environmental Design class in first year only	
			The integration of sustainable design into course material is professor not program driven. There is no formal education program integrating sustainable design but many profs in a number of different programs are starting to integrate as a result of professional or personal interest.	
3 - Which sustainable design strategies, if any, does your program teach?				
We do not teach sustainable design		0	13.33%	2
Leadership In Energy and Environmental Design (LEED)	85.7%	6	53.33%	8
Biophilia	28.6%	2	20.00%	3
Biomimicry	57.1%	4	60.00%	9
Other (please explain)	28.6%	2	26.67%	4
answered question		**7**		**15**
skipped question		1		1
Respondent Comments	Energy performance, resilience, longevity, reduction, etc.		Green Building	
	I can't really speak to this because I do not know exactly what my colleagues teach. Yes, it is quite likely that the design faculty include biomimicry and perhaps biophilia in their teaching. Faculty generally do not know exactly what / how other faculty members teach in their classes and studios. Similarly, I checked LEED but I don't know exactly either what you mean or what my colleagues do. We do not teach LEED but I do know that several of my colleagues have the LEED AP accreditation so it likely affects their teaching. If you mean do we train students specifically to take the LEED exam, then the answer is 'no'.		Cradle to Cradle paradigm, human centered design methods from IDEO for social sustainability	
			Sustainable topics related to engineering technologies	

Answer Options	Response %	Response Count	Response %	Response Count
4 - In what context does or will your program integrate sustainable design strategies?				
We do not teach sustainable design		0	7.14%	1
Design application	83.3%	5	42.86%	6
Construction specification	50.0%	3	35.71%	5
Methods and materials	100.0%	6	64.29%	9
Interdisciplinary methods and models	33.3%	2	50.00%	7
Other (please explain)	16.7%	1	21.43%	3
answered question		**6**		**14**
skipped question		2		2
Respondent Comments	I really don't know what my colleagues do. I'm quite sure that one colleague integrates sustainable design strategies into Methods and materials but I'm not sure about others. It might be a better survey strategy to ask faculty about what they themselves do (I myself do not teach design studio per se).		The program does this in a number of course and in studios - courses are materials, indoor systems, sensory technology, and studios in the Masters & Interiors Option	
			For research and design exploration	
			We teach a number of resource and industrial design sustainability. This is where the biomimicry material comes into play - not really from a design perspective but as an introduction to the types of things that resource and business managers need to be aware of when trying to drive innovation in their organizations.	
5 - If your program does not teach bio-design strategies is it because?				
The educators are not familiar with bio-design	100.0%	2	10.00%	1
Bio-design is too advanced for under-graduate		0	10.00%	1
The curriculum is sufficiently full and can't accommodate any more content		0	50.00%	5
The curriculum is challenging the students enough without adding biology		0	20.00%	2
It is not a topic that students ask for		0	10.00%	1
Other (please explain)		0	50.00%	5
answered question		**2**		**10**
skipped question		6		6
Respondent Comments			We do teach them	
			LEED is in the curriculum. Biomicthis is a topic that would be added per a professors own under taking. We do have LEED in our curriculum. Biom isn't a program subject target.	
			We do discuss it.	
			Formal "design" isn't part of our curriculum.	
6 - How long has your program been integrating bio-design strategies into its courses?				
We do not integrate bio-design into our curriculum (skip to Question 10)	16.7%	1	35.71%	5
Less than 1 year		0		0
1-5 years	33.3%	2	14.29%	2
More than 5 years	50.0%	3	50.00%	7
We no long teach bio-design (please explain)		0		0
answered question		**6**		**14**
skipped question		2		2

Answer Options	Response %	Response Count	Response %	Response Count
7 - What percentage of students apply bio-design strategies satisfactorily?				
More than 75%	25.0%	1	33.33%	3
50%-75%	50.0%	2	33.33%	3
Less than 50% (please explain)	25.0%	1	33.33%	3
answered question		**4**		**9**
skipped question		4		7
Respondent Comments	It is only part of projects, and when there is an option students may use another theory.		They are still at a very basic level in application, but use Biomimicry for research, and as a measure deeper than application.	
			As an undergrad program, we find out student focus more on understanding just the principles of design and presentation of the design vs. the sustainability. Though we do have an entire studio where students need to develop a house with sustainable strategies, though they are very elementary at this stage in their design development.	
			Most just see it as 'one' option	
8 - What do you see as the 'go to' resources that your students employ to understand bio-design?				
Websites	60.0%	3	77.78%	7
Google Scholar	40.0%	2	22.22%	2
Books and publications	60.0%	3	66.67%	6
Industry case studies	20.0%	1	55.56%	5
Practitioners	20.0%	1	44.44%	4
Their peers	20.0%	1	11.11%	1
Students in other disciplines		0	11.11%	1
I don't know	20.0%	1		0
Other (please explain)	60.0%	3	33.33%	3
answered question		**5**		**9**
skipped question		3		7
Respondent Comments	USGBC local chapter events/meetings		Professors knowledge	
	AskNature.org		I am the teacher and I have a Biomimicry Specialist certificate as well as AskNature.org	
			My lecture notes and the materials that I give them or direct them to.	
9 - What challenges do your students express when applying bio-design strategies?				
Understanding how to apply biology into design	80.0%	4	33.33%	3
Understanding the difference between biophilia and biomimicry	20.0%	1	22.22%	2
Understanding bio-design nomenclature	40.0%	2	11.11%	1
Understanding interdisciplinary design strategies	20.0%	1	33.33%	3
Understanding interdisciplinary vernacular	20.0%	1	11.11%	1
Working with other disciplines	20.0%	1	11.11%	1
Locating bio-design expertise or resources	40.0%	2	55.56%	5
Understanding what biology brings to design problem solving	60.0%	3	33.33%	3
Other (please explain)	20.0%	1	33.33%	3
answered question		**5**		**9**
skipped question		3		7
Respondent Comments	I don't teach these classes. I'd only be guessing what my colleagues do.		I see the problems in conceptualizing	
			Although this is overcome very quickly as students have quite a lot of knowledge and interest in these topics	
			Getting past bio-morphic design only and concentrating on the functional aspects of organisms	

Answer Options	Response %	Response Count	Response %	Response Count
10 - Interdisciplinary design strategies are important to the successful execution of bio-design methodology. Does your program teach interdisciplinary tactics?				
YES, by:	80.0%	4	33.33%	3
Opening the courses up to other disciplines	60.0%	3	66.67%	6
Introducing problem-solving methodologies from other disciplines	60.0%	3	56.55%	5
Teaching and/or developing an interdisciplinary language	80.0%	4	33.33%	3
Encouraging your students to attend courses in other disciplines to understand their methodologies	80.0%	4	44.44%	4
NO, because:		0	22.22%	2
Involving students outside of our program is too complex to administer	20.0%	1	11.11%	1
Other disciplines have shown any interest in our program		0	11.11%	1
Introducing problem-solving methodologies from other disciplines is too advanced for our students		0		0
We don't have the educator resources to teach it		0	11.11%	1
Our curriculum is full		0	11.11%	1
Other (please explain)		0	11.11%	1
answered question		**5**		**9**
skipped question		3		7
Respondent Comments			the LEED course is interdisciplinary	
11 - What other faculty's students are invited to participate in your program's course(s)?				
I don't know of students from other faculties participating in our program	20.0%	1	11.11%	1
Architecture	40.0%	2	66.67%	6
Engineering	20.0%	1	33.33%	3
Business	20.0%	1	22.22%	2
Science	40.0%	2	44.44%	4
Other (please explain)	60.0%	3	55.56%	5
answered question		**5**		**9**
skipped question		3		7
Respondent Comments	Industrial design , interior design & graphic design		Any that are interested	
	Our materials and specifications course that introduces biophilia and biomimicry and LEED is open to anyone at the university		Music students and landscape architecture students	
	Environmental psychology, ergonomics are part of our department. We are inherently interdisc under one roof		Fish and wildlife students	
			Our school is small and is a closed program	
			Our courses are for our students only, as they have to be accepted into our program. All degree students can select from the elective pool of courses for their electives	

Answer Options	Response %	Response Count	Response %	Response Count
12 - What challenges do your design students experience when incorporating interdisciplinary concepts?				
We do not have interdisciplinary students in our program		0	44.44%	4
Understanding terminology	60.0%	3	22.22%	2
Letting go of design authorship (sharing ownership)	20.0%	1	22.22%	2
Understanding other disciplines' problem solving methodologies	40.0%	2	11.11%	1
Respect among the interdisciplinarians	20.0%	1	11.11%	1
Cooperation of the interdisciplinarians	60.0%	3	11.11%	1
Other (please explain)	20.0%	1	22.22%	2
answered question		**5**		**9**
skipped question		3		7
Respondent Comments	Negotiating shared values, goals and language		I am guessing here because I don't teach the LEED course	
			It hasn't been a huge challenge, they usually work well as a team and respect each others perspectives.	
13 - Do any of your courses integrate biomimicry?				
Not at this time (skip to Question 24)		0	50.00%	7
1 course	60.0%	3	21.43%	3
2-4 courses	40.0%	2	28.57%	4
More than 5 courses		0		0
answered question		**5**		**9**
skipped question		3		7
14 - Which level of study do the students best comprehend and apply biomimicry?				
It is only taught at the undergraduate level	40.0%	2	28.57%	2
It is only taught at the graduate level		0	14.29%	1
Both undergraduate and graduate equally well	40.0%	2	42.86%	3
Not sure, we are still accessing the outcomes	20.0%	1	14.29%	1
answered question		**5**		**7**
skipped question		3		9
15 - In what environments do you find teaching biomimicry to be the most effective?				
Lecture	33.3%	2	85.71%	6
Lab	33.3%	2	42.86%	3
Studio	66.7%	4	28.57%	2
Field study	16.7%	1	14.29%	1
Online		0	14.29%	1
Other (please explain)	16.7%	1	14.29%	1
answered question		**6**		**7**
skipped question		2		9
Respondent Comments			It is a workshop and lecture-based course	
16 - Is biomimicry integrated into other courses outside of your program at your institution?				
I don't know	83.3%	5	42.86%	3
No		0	14.29%	1
Yes (please explain)	16.7%	1	42.86%	3
answered question		**6**		**7**
skipped question		2		9
Respondent Comments	Optimal healing environments course at the graduate level		It is an approach that can be used in studios as a methodology	
			I think in EVDS	
			A very little bit in the engineering depart.	
17 - What techniques are most effective in teaching biomimicry?				
Design Spiral methodology	33.3%	2	16.67%	1
Charrette	16.7%	1	16.67%	1
Competition	16.7%	1		0
Field study	16.7%	1	33.33%	2
Case studies	83.3%	5	66.67%	4
Modelling		0		0
Taxonomy (a catalogue of biology-based	33.3%	2	50.00%	3
Other (please explain)	16.7%	1	16.67%	1
answered question		**6**		**6**
skipped question		2		10
Respondent Comments			Unsure, I don't teach these courses	

Answer Options	Response %	Response Count	Response %	Response Count
18 - How do your students react to biomimicry?				
Positively	66.7%	4	85.71%	6
Negatively		0		0
Indifferent		0		0
Other (please explain)	33.3%	2	14.29%	1
answered question		**6**		**7**
skipped question		2		9
Respondent Comments	They are very excited once they understand. The love for nature as a result of studying nature makes them want to save nature!		Some of the penchant for it - some think its irrelevant. Depends on the student	
	I do not teach biomimicry.			
19 - What challenges have you experienced when teaching biomimicry?				
There are no unique challenges	33.3%	2	50.00%	3
Teaching the concepts	16.7%	1		0
Teaching biology in a design context	33.3%	2		0
Student comprehension	16.7%	1		0
Student application	50.0%	3		0
Measuring the outcomes	16.7%	1	16.67%	1
Other (please explain)	16.7%	1	33.33%	2
answered question		**6**		**6**
skipped question		2		10
Respondent Comments	I myself do not teach biomimicry		Understanding the biology at a functional level	
20 - Do you measure the outcomes of integrating bio-design into the coursework differently than other topics?				
No	100.0%	5	100.00%	7
answered question		**5**		**7**
skipped question		3		9
21- What model(s) does your program employ in delivering sustainable design courses?				
On-campus	100.0%	5	100.00%	6
Online		0	16.67%	1
Mainly on-campus but we are considering online		0		0
answered question		**5**		**6**
skipped question		3		10
22 - Do your educators find sustainable design courses more challenging to deliver online?				
No	50.0%	2	66.67%	4
Yes (please explain)	50.0%	2	33.33%	2
answered question		**4**		**6**
skipped question		4		10
Respondent Comments	Unsure; they are not offered online at this time		We haven't tried it yet	
23 - What advice, if any, would you give educators planning to integrate bio-design strategies into their design curriculum?				
	100.0%	3	100.0%	5
answered question		**3**		**5**
skipped question		5		11
Respondent Comments	Visual aides essential		Keep up to date!	
	Talk with people who have done it		Just do it	
	Have them fall in love with nature. Take them into nature, show them what nature does, them have them design based on the awesomeness of nature!		Just get started, even the introduction to learning from nature starts many great conversations	
			Get onto it quickly, it is an expectation in 2014 & required by CIDA	
24 - Does your program forecast adding bio-design strategies into the design curriculum in the foreseeable future?				
Yes, within the next year	40.0%	2	14.29%	1
Maybe, in the next 1-2 years		0	14.29%	1
No (please explain)	60.0%	3	71.43%	5
answered question		**5**		**6**
skipped question		3		10
Respondent Comments	Already doing it		We are already doing it	
	Currently doing it		Integrating bio-design is professor driven not program driven	
			We already do	
			We are busy trying to meet with CIDA accreditation and practice act deadlines...will not think of it for a few years.	