Prototyping learning and congruence in new realities

by

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The student author and program of study committee are solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

To my gangbusters family.

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NOMENCLATURE

AR	Augmented Reality
CAD	Computer Aided-Design
CAM	Computer Aided-Manufacturing
CNC	Computer Numerical Control
DIY	Do It Yourself
FLEx	Forward Learning Experience
FOV	Field Of View
HMD	Head Mounted Display
IoT	Internet of Things
GUI	Graphical User Interface
NUI	Natural User Interface
PLTW	Project Lead The Way
OBJ	Geometry definition (open) file format by Wavefront Technologies
STEM	Science Technology Engineering and Math
SVG	Scaled Vector Graphic
UI	User Interface
VR	Virtual Reality
XR	Variable or Extended Reality

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ABSTRACT

The educational system in the industrialized 20th Century, a monolithic delivery model, prepared students for a hierarchical livelihood in either blue collar or white collar worlds. Today, a different landscape is predicted for the workforce. And it is rapidly changing and advancing. Will Richardson points out that by 2020 more than half the US workforce will be “freelancers, consultants and independent workers” (Richardson, 2012). While forecasts and predictions vary, continuing studies support this workforce evolution.

The continued revolution in digital technology is pervasive today with mobile devices and the Internet providing an abundance of information, knowledge and opportunity with the potential for a student customized learning experience. Anticipating this shift, Richardson recognizes the need for students to master learning instead of content as is assessed currently. This situates well with John Seely Brown describing “agency” as active participation, creating and building as a principal attribute of a student in this new educational model while inscribing “empathy” as a second requisite quality (Brown, 2013).

A new strategy for learning, understanding and doing is required that encourages agency with individuals actively experiencing new technologies and realities for creating and communicating that support deeper experiences and shift perspectives in ways not possible before. This is required to imbue discovery, creativity and new craft toward the most appropriately designed solutions in a highly technological and evermore complex world. Universal Constructs, with new tools for seeing and making, become the framework to weave design thinking, STEM and 21st Century Skills together holistically to better define the potentials for learning, understanding and doing.

A pilot program called the Forward Learning Experience (FLEx) was launched in 2014 with the intention to introduce the framework above to students today. As of July 2017, the FLEx has reached almost 45,000 constituents of Iowa, primarily K-12 students, and has undergone initial reviews with positive results showing its potential capacities toward a new educational and learning model.

Leading students with forward looking experiences, strategies and frameworks through the FLEx or similar opportunities to augment core skills through emergent technologies for seeing

and making through robust multi-mode neuro-phenomenological means will enable a new calculus for deeper learning, understanding and impactful doing with extended imagination, empathy and ethics.

CHAPTER 1 INTRODUCTION

Prologue

Why me? Why now? Why is this important?

The principle reasons this thesis evolved were due to timing, perspective, my experience through school as a student, professional practice as an architect, and then as a teacher at Iowa State. Having graduated with a bachelor of architecture degree from Iowa State in 1995, I was at the start of the transition from paper tools and hand renderings, through CAD tools to 3D tools with photorealistic and animation capabilities. I had adopted 3D visualization and production tools faster than most classmates and colleagues, partially because I saw a value to them and they also seemed natural to me. I also saw the conflict firsthand between the existing business needs, existing business models and prevalent deliverables, and formal instruments of service.

Early in my career as an intern architect while I was working at Brooks Borg Skiles Engineering, I had the opportunity to be the principal designer on a key virtual reality project at Iowa State. I worked for the Virtual Reality Application Center while Carolina Cruz-Neira, Jim Bernard and Jim Oliver were leading the center to the world's first 6-sided virtual reality CAVE—VRAC C6 Research Installation. I had identified the moment where Iowa State had a first of its kind opportunity with virtual reality with the radical work Lebbeus Woods espoused. He was irreverent but clear in his vision for breaking conventional limits and setting new rules. Just as important, during the development of the design, I was given a virtual tour of the 3D digital design model that I authored in a predecessor to the C6, which floored me. In my estimation, I was seeing what was in my head all around me, and my body was in it along with one of the VR leaders at VRAC. It was a major transformative experience.

However, it wasn't only through this event or project work that this thesis developed. I had other formative personal experiences in martial arts and the Iowa National Guard as a paratrooper in a long range surveillance unit. In HapKiDo, I worked around ideas of mutual trust and benefit and personally understood proprioception and awareness in new and elevated ways. The experience as a paratrooper literally provided a lens of the earth from 1000' above, and we worked hard on the terrain through many combinations of land navigation, movement, optimized perspective, and multiple view angles. We took it upon ourselves not to accept any status quo

aiming very high with expectations, performance, standards, and esprit de corp. These experiences provided a strong sense of agency.

The professional design setting also provided me with first hand experiences, seeing change in business as technology provided what I thought were great opportunities. Yet the desire for change seemed minimal in most circumstances. I took an opportunity to volunteer with the Technology in Architectural Practice (TAP) knowledge community in the American Institute of Architecture where TAP awarded advanced implementations of technology in many ways each year at a national level. This exposure provided witness that change was occurring in specific circumstances, even if I did not see it happening quickly in the Midwest.

This also mixed with a few unique opportunities where I was able to continue working with the fabricators of the VRAC C6. I was asked to realize large-scale metal artwork digitally and to provide fabrication CAD for almost unbuildable criteria. I created workflows to realize this art from very advanced 3D surfacing to flatwork that could be CNC cut and CNC rolled back to complex physical art forms.

This desire to work at the edge of practice, while it did not evolve rapidly enough, sent me to teach at Iowa State. I believed I could help students in design prepare for their future and change the profession in a more proactive manner. This happened in some circumstances, but mostly there was an aversion to change in higher education. Not from the students, but from the curriculum and other faculty. Some supported change, some did not, and, as a lecturer, my opinion was somewhat marginalized.

I believed, if change were to occur in learning with the changes I felt I saw happening around me, it needed to be even earlier than higher education. Many ideas of advanced design technologies for seeing and making formulated as an outreach idea.

Simultaneously a new discipline had started at Iowa State called Industrial Design, which I found very appealing. For one, it was a broader discipline than architecture but with many shared design principles. It was also much more innovative in its breadth of process and ultimately in many of its products. Not only could I understand space in an analytical and synthetic framework from architecture, but I could work with objects, things, and people in an new way. Architecture is moving forward with building information modeling, simulation, and

computation, and now I can see all those tools and potentials better. But Industrial Design best blended an opportunity to design and to make which has become a tenet in how a Forward Learning Experience (FLEx) could help shape a learner's perspective with emerging technology.

So is this really important for youth to have in addition to their classwork?

STEM has picked up momentum while the FLEx has evolved. Some of that due to career and technical pressures for future-ready jobs by the government. Along with this, some large curriculums have been adopted such as Project Lead The Way (PLTW) which reinforce a formal structure. But these are gateways to engineering and only applicable for some students and a redoubling of efforts to keep "the solution" in the schools.

As the Forward Learning Experience evolved, I found the learning theories discussed in the thesis supported the project. Many conversations with Iowa Area Education Association experts and state Department of Education consultants showed a recent trend line with reverse, flipped, competency-based, project based, and blended classes beginning to enter the general discussion. This all helped me to understand the limits of what a classroom today can provide.

One of the specific things the FLEx does is match these trendlines. The FLEx does not add to the classrooms requirements, but lets the students be released from those conditions for a respite. I have called FLEx an informal space. An intellectual recess, not in the sense of leaving the intellect for class time, but letting it be free to explore and experiment and even play in a stimulating, supportive manner. It is rewarding to watch a classroom of students arrive at the beginning of a FLEx event reserved and quiet, but to leaving as animated, engaged and responsive individuals.

This is in sync to what I have felt for years. Our society is at peril if we ignore technological changes in learning. Computer technology has rapidly advanced and even shown an accelerating rate of change in many ways. This has been in direct conflict to many professions, industries, and institutions. It can fundamentally change how a business model works, thrives, or dies. This technology is proving to be central part of a radical innovation that has largely redefined some areas of society with many other areas likely to follow.

Think of it like a sport where one is throwing a ball to a receiver is who running. It is a moving target situation. You have to throw the ball ahead of the receiver so the two moving objects, the ball and the receiver, can intersect with a successful completion. This analogy speaks to the situation education and learning face along with the rest of society. I believe this was not the condition a generation or two ago in our culture. What was more static and stable then is now much more dynamic. Clayton Christiansen and Will Richardson, among others, speak to this issue quite well. This, too, is what the FLEx is intended to do and address which is to put emerging technologies in the hands of everyone needing to understand and contextualize these technologies. Particularly youth and students. It isn't even the students at that moment who have the experience that matters, it is the ***transformative potential*** that the student has understanding themselves using these ideas and technologies in their future that is important, anticipating that the technology will evolve around them.

If formal education is to succeed in the future, it will have to find ways to integrate more informal opportunities for the learner. There will be core materials that a student will need to master, but as Will Richardson suggests, the student will master learning themselves and optimally be in a student-centered learning environment. The student may even be bringing more informal experiences to a classroom to build upon with core knowledge than using the classroom as a central repository to grow from.

The ideas in this thesis and in the FLEx support a bridge between formal and informal learning where the tools for learning are not only coming from the classroom, but also surrounding the students daily providing the student a way to see themselves through these new powerful emerging tools.

CHAPTER 1 Summary

There is major shift in culture impacting how work is accomplished and many other facets in life. This is in large part to due to advances in technology. Different disciplines are sharing toolsets and processes and now emerging toolsets are impacting work processes, products and collaborations in new ways. The entire workforce is undergoing a massive shift. This is also directly challenging institutions such as education. Education expectations and opportunities today are vastly different than they were in the 20th century.

Chapter one includes an introduction and discussion of the different conditions creating the environment, priming the need for a new platform for the 21st Century STEM-based design technology and thinking. Chapter Two includes a review of appropriate educational theories impacting this new platform. Chapter Three reviews maturing theories on presence, awareness, related topics and the impact on empathy, ethics and problem solving. Chapter Four looks at emerging toolsets and how they are impacting ways to SEE and MAKE solutions will help define a Forward Learning Experience and why it is important for today's population. Chapter Five describes more explicitly how the Forward Learning Experience operates and addresses these conditions. Chapter Six completes the discussion on the Forward Learning Experience today and proposes the next steps in its direction and anticipated evolution.

Introduction

In Clayton Christiansen's book, *Disrupting Class* (2017), a summary is provided of the history of American Schools from the inception to current day. He wrote, "Education's first job was to preserve the democracy and inculcate democratic values." From this point through the 20th century, the single classroom advanced to what Christiansen describes as the "monolithic delivery model" where schools became very large and expectations for high school graduation rates for the general population became the expected condition preparing students for vocations and professional careers. He also used the description "monolithic delivery model" for the experience of every student in a classroom where the instruction was standard for every student and the classroom model instructed all students equally. (Christiansen, 2017) This classroom model of instruction has also been questioned and criticized by several scholars (Papert, Harel, 1991, 1993; Pea, 1993; Lave & Wenger, 1991).

This industrial era 20th Century education prepared students for a hierarchical livelihood in either blue collar or white collar worlds. One path of education prepared individuals more for factory oriented work, manual trades and industries (blue collar). A second strove to prepare thinkers, directors, designers, teachers, planners and professionals (white collar). A factory-based education was very career oriented and very specialized even in its foundations towards a specific end (Richardson, 2012).

Today, digital technology is pervasive with mobile devices and the internet, providing an abundance of information, knowledge, and opportunity. Will Richardson, in his text, *Why School: How Education Must Change When Learning and Information are Everywhere* (2012), points

out that by 2020 more than half the US workforce will be, “freelancers, consultants and independent workers.”

This lines up with today’s workforce trends where more and more jobs are part-time, forcing many working individuals to work multiple jobs and shift through several career changes. While forecasts and predictions vary, continuing studies support this workforce evolution (Horowitz, S., 2015; “Labor,” 2012; Toossi, M., 2015; Dourado, E., Koopman, 2016; Konrad, M., 2015).

Will Richardson also notes a shift in students needing to master content to being able to master learning. This is in large part because schools are not the gatekeepers to knowledge anymore. The confluence of digital technologies like smartphones and the internet have provided a wealth of accessible information and knowledge to over 2 billion connected people. This number is predicted to increase to 5 billion by 2020, according to Richardson. This has created an abundance of information in contrast to when schools and libraries were the delivery platform of this scarce knowledge in the 20th century. In this circumstance, Richardson points out, teachers, students and all learners need to share and participate in their learning and even the path of their learning. Assessments today, often focusing on what learners know, should be shifting to what is done with that knowledge. Richardson writes, “In times of great change, learners will inherit the earth, while the learned will be beautifully equipped for a world that no longer exists.” (Richardson, 2012) A very important corollary that Richardson recognizes and discusses, but does not emphasize enough in his text, is that the learning will be very digitally oriented and it will also evolve rapidly through the education and working adult life of students today and onward.

A pertinent anecdote related to the digital orientation, dramatic changing workforce and an immediately relevant job platform is Industrial Design. According to design leaders and thinkers at leading US design firms, interviewed by John Brownlee of Fast Company in 2016, classically trained and “Traditional Industrial Designers” are at risk (Brownlee, 2016). Design cannot be done in a vacuum where the form and sculptural aspects, values that once led the market, are not enough now and in the future. These will be “designosaurs” according to Mark Wierzoch, design director at Artefact. Traditional Industrial Design was identified as one of five design jobs that will not exist in the future. And later in the same article, “Post-industrial Designer” will be a growing segment from this domain. The future industrial designer will be responsible for

connected contexts and end-to-end experiences building “tangible experiences that connect the physical and digital worlds,” says Wierzoch (Brownlee, 2016).

This shift, focusing from only more traditional classroom instruction and curriculum, formal core knowledge & STEM, will have to become a more holistic approach, incorporating habits of mind and Universal Constructs within 21st Century Skills. This closely and clearly also aligns with a base concept John Seely Brown has put forward with two requisite concepts: (1) “agency” as active participation, creating and building and (2) “empathy” as a second requisite quality in current and future students. (2009)

Another large and advancing factor is one written about at the change of the century. E.O. Wilson wrote of consilience in 1999. He defined this as, “The way in which different fields connect in terms of the basic laws that they share together.” (Wilson, 1998) He predicted the 21st century to be a time of consilience between the arts and sciences. (Wilson, 1998) In the same classroom college students ranging from architecture to industrial design, to mechanical and aerospace engineering take the same or similar CAD & CAM software and use similar processes for digital and physical prototyping. The ways to use these new processes are very different than decades ago and also impact the project results and deliverables in large ways. These same challenges and opportunities are happening in the workforce (Evans, P., 2003).

Consilience now also speaks to the extended modes and mediums available from digital communication to digital prototyping and real prototyping. From the architecture side of design, “Architecture no longer only deals with enclosed space or that of a city and its buildings but it also deals with psychological, virtual, or electronic space.” (Knobe, Noennig, 1999). Many disciplines are beginning to recognize new toolsets and ways of accomplishing their problem set in new ways, and these new ways are simultaneously providing new problem sets that were not opportunities before.

This thesis focuses on the tools and frameworks required to positively impact these underlying conditions as new foundations for an idealized individual that this and future society requires to solve evermore complex problems. This foundation is one that is not generalized in this idealized state but situated in each individual to their idealized and forward potential.

In particular, applying correct learning theories to emerging reality tools such as VR, AR, and XR positioned alongside new CNC craft, fabrication, and production concepts will provide direct capacities to increase agency, imagination, empathy, and ethics.

CHAPTER 2 EDUCATION AND LEARNING THEORIES

CHAPTER 2 Summary

There are several well accepted educational and learning theories that are meaningful and support this thesis. They recognize and attempt to redress the deficiencies in the typical educational standards and 20th century classroom settings. They are also recognized partially in response to the early days of digital technologies and in some settings have already been integrated into an educational setting. These are learning theories that encourage deeper and personal learning. They include Experiential Learning, Constructivism, Situational Cognition and 21st Century Skills as fundamental theories. They have developed a necessary skillset in the 21st century which recognizes the individual with differences in learning intelligences and even a design for learning that incorporates a universal perspective addressing the needs of each learner.

By studying the consistent values these theories place on the individual learner and in particular, the unique prior knowledge, experiences and affordances in which the learner benefits, we can then evaluate how they impact a 21st century learner in new realities such as VR, AR, and XR and how these emerging tools will be important to the learner in their future.

Constructivism

Knowledge is built individually through experience and interaction both directly and indirectly in an active and contextual process (Piaget, 2013). This is done over a lifetime. Constructivism recognizes that this knowledge is personal from that experience, and new knowledge is continually built and developed on top of previous experience and social interactions (Ertmer, P. A., & Newby, T. J. (2013); Cooper, P. A., 1993). Lev Vygotsky developed the foundations for constructivism through his three major child development themes in his social development theory: (1) social interaction, (2) the More Knowledgeable Other (MKO) and (3) the Zone of Proximal Development (Vygotsky, 1978). In all themes, the child or student plays an active role in the learning process, rather than being a passive recipient of information transfer.

“People actively construct or create their own subjective representations of objective reality. New information is linked to to prior knowledge, thus mental representations are subjective.” (“Constructivism”, 2016)

Experiential learning

In 1984, David Kolb built on work by John Dewey and Kurt Levin where “learning is the process whereby knowledge is created through the transformation of experience” (Kolb, D. A., 2014) in four cyclical modes of learning with four stages: (1) Concrete experience where the learner is in an active “Do” stage, (2) Observation and Reflection places the learner in conscious reflection on the experience in an “Observe” stage, (3) Abstract Conceptualization has the learner conceptualizing a model or theory of the observation in a “Think” stage & (4) Active Experimentation places the learner in a new situation testing the new theory or model in a “Plan” stage (Kolb, D. A., 2014).

One notable aspect of this learning theory is that a learner could enter at any point and continue through the stages. And Kolb also built learning styles that follow these learning stages. They are: Assimilators (sound logic theory learners), Convergers (applied practice model learners), Accommodators (“hands-on” learners) and Divergers (observing and collecting learners) (Kolb, D. A., 2014). This is important in that multiple learning styles are recognized and offered in the multiple stages and styles. There will be more discussion on multiple learning styles toward the end of Chapter 2.

And Experiential Learning dates back to early work in the 20th Century by John Dewey (1938) where he recognized the importance of personalized learning by building on prior personal experiences. He also noted the importance of profound experiences that can shift perspective (Dewey, 1934). Recently, Pugh and Girod transformed this early work to the sciences (Pugh, Girod, 2007; Goodman, 2015). And then in 2011, this profound experience is labeled as a transformative experience with three key components: 1. Motivated use; 2. Expanded perception and 3. Affective value (Pugh, 2011; Goodman, 2015). In Pugh’s work, these components are resultant or reinforced from formal curricular work and exhibited outside of the school room. It may be even more transformative for education to consider that these events may reverse in sequence occurring outside the formal educational setting. And with expanded perception, affective value, and motivated use (agency), be more primed in the classroom for reinforced and scaffolded learning.

In summary, Experiential Learning is a multiple stage learning theory that includes direct experience, observation, thinking and planning and recognizes different learning styles for the different stages such as convergent and divergent learners. It recognizes the individual

experience, scaffolding and, importantly, the impact of a profound shift in perspective called a transformative experience which includes the importance of motivated use or agency, expanded perception and an affective or empathic value.

Situated Learning Theory

Similar to Experiential Learning in some ways, Situated Learning Theory posits that knowledge is embedded how and where it is learned. This includes the activity, the context and the culture (Robbins, P., & Aydede, M., 2013; Brown, J. S., Collins, A., & Duguid, P., 1989). The situated learning is not isolated or abstract but understood better in its applied and most direct and authentic situational use. In a social framework, the novice learner, described as a "cognitive apprentice," is learning from the expert or practitioner directly doing the activity, and the expert recognizes that novice's previous experience that may apply to the activity to best scaffold the learning environment.

Situated cognition states "knowledge is embedded and constructed in the activity, context, and culture in which it is learned."

So Constructivism, Experiential and Situated Learning are complementary and applicable to contemporary learning and thinking: "Understanding is in our interactions with the environment" and "meaning exists as it is constructed… shifting the focus of learning design... in which learners will interact." VR, AR, and XR offer a wide range of (digitally) constructed opportunities and conditions for learning context and content in addition to physical construction and other modes of representation. (Muecke, M. and Evans, P., 2014).

21st Century Skills

The Common Core, which was created in 2009 ("Development", n.d.), is a state-driven education standards system to keep students from one core standards state on track with peers in another core standards state. The Iowa Core is the state of Iowa version of the Common Core. One aspect of the Iowa Core is the initiative for 21st Century Skills. These are skills that are not standards based, such as core subjects like math and science, but include life, learning and career skills. They include many skills, or attributes, such as agency, leadership & responsibility; civic, environmental, financial, media, information and health literacy; and learning/innovation ("21st Century Skills", n.d.). These skills also incorporate Universal Constructs which are competencies sometimes referred to as the 4C's (creativity, critical

thinking, collaboration and complex communication). In addition to the 4Cs, there are also flexibility and adaptability, and productivity and accountability ("Universal", n.d.). The 4C's are a part of the educational framework presented with the Forward Learning Experience and will be discussed more thoroughly in Chapter 5. All the 21st Century Skills are designed to complement the 21st century student around the core content areas in interdisciplinary ways throughout their primary and secondary education. ("Universal", n.d.)

Universal Design for Learning, Learning Styles and Modes of Understanding

Universal design for learning (UDL) is a framework to improve and optimize teaching and learning for all people based on scientific insights into how humans learn. UDL focuses on the individual learner recognizing different learning modes, aptitudes and needs.

Howard Gardner developed the theory of multiple intelligences which have developed into a well defined description of eight learning styles. This extends the idea of UDL further into educational learning theory, recognizing and treating students more uniquely. The eight learning styles are: musical-rhythmic, visual-spatial, verbal-linguistic, logical-mathematical, bodily-kinesthetic, interpersonal, intrapersonal, and naturalistic. Gardner has also included existential and moral intelligences and very consciously intends these styles to empower learning and no restrict or label a single modality for a certain learner (Gardner, H., 2011).

Recognizing that each learner is unique and coming from different backgrounds is key. Every student learns differently. Offering diverse students a broad spectrum of learning opportunities provided by a range of learning tools will potentially lead to a more comprehensive and effective level of learning for all of the students. The Universal Design for Learning (UDL) initiative[ii] acknowledges three brain networks involved in effective learning. They consist of recognition networks (the 'what' of learning - arbitrary things), strategic networks (the 'how' of learning - meaningful relationships), and affective networks (the 'why' of learning - explanations) ("What is Universal Design for Learning", n.d.). These distinct brain networks are also recognized through human computer interface work in parallel and complementary processes to UDL, where the 'what' is declarative knowledge and the 'how' is procedural knowledge (Dix, 2011).

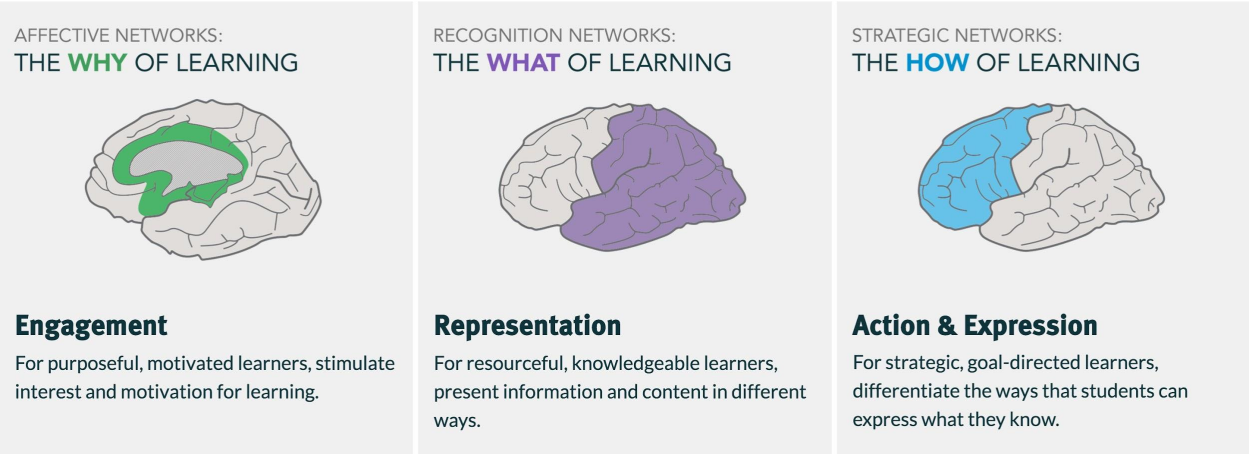

FIGURE 1 - UDL AFFECTIVE NETWORKS
From http://www.cast.org/our-work/about-udl.html#.WXATJdPyuSN

Cognitive psychology has observed that working memory holds both verbal and visuospatial information (Wickens, C.D., Lee, J., & Liu, Y., 2004). Beyond that, long-term memory, or internalized knowledge, describes comprehension (Wickens, C.D., Lee, J., & Liu, Y., 2004). So bringing UDL principles consciously into the design curriculum may also create more complex evaluation from the students' perspective (analogous to cognitive processing), which in turn might allow more resonance and/or more opportunities for some students to gain more profound insights into design and thinking processes.

UDL principles are a fundamental means to strengthen the multimodal/sensory delivery of learning methods and understandings in addition to recognizing the individual learner and diverse learning styles which are further reinforced by Gardner's multiple learning intelligence and learning styles.

Bloom's Taxonomy and Depth of Knowledge

In 1956, Benjamin S. Bloom, and educational psychologist, published a hierarchical model of thinking with six levels of cognitive complexity. This allowed for a differentiation of thinking in terms of lower and higher levels of thinking defined from low to high as knowledge, comprehension, application, analysis, synthesis and evaluation ("Bloom's Taxonomy", n.d.; Bloom, 1956) This model was updated in 2001 to account for 21st Century needs (Anderson, L.W., Krathwohl, D.R., Bloom, B.S., 2001) The revision adjusted the levels of thinking from low to high as remembering, understanding, applying, analyzing, evaluating, and creating. The hierarchy allows a way of understanding knowledge mastery with a goal of achieving it at the

highest level. Another view of these levels of thinking from low to high are from passive to active learning, or even from a monolithic model of thinking to a student centered learning model.

Depth of Knowledge (DOK) provides a framework for assessing how students think in terms of the process and occurs from low to high as recall and reproduction, skills and concepts, strategic thinking/reasoning, and extended thinking ("2 Thinking frameworks", 2017; Robin, 2017; "Blooms-vs-webb-chart", 2017).

In both Bloom's (revised) Taxonomy and the DOK, the process of thinking is the focus rather than the product or answer as a more formative measure of knowledge and thinking. The two systems are currently used together for curriculum development and assessment with both targeting higher learning or thinking with the understanding that achieving the higher level will incorporate the lower levels as well. One interesting note in the DOK is an acknowledgement of time and reflecting that time may be required for extended thinking and that this may not occur by repetition, but requires the learner understand multiple solutions, connections or even perspectives (Robin, 2017).

Connecting the DOK, Bloom's (revised) Taxonomy, UDL and additional learning theories becomes a clear bridge to how an individual learns and the importance of the environmental factors directly to that learner. Each individual learner is different, their context matters for learning, and deeper learning and extended thinking can occur if primed and even situated appropriately. And this is in sharp contrast to the 20th Century factory-based model. In addition, an understanding of multiple solutions, connections and perspectives further enables these desired learning states. These multiple modes of personalized understanding, including through VR, AR, and XR, will be discussed in Chapter 3.

CHAPTER 3 REAL TO VIRTUAL CONGRUENCE

CHAPTER 3 Summary

The CAVE was invented in 1992 at the University of Illinois, Electronic Visualization Laboratory. (Cruz-Neira, C., Sandin, D.J., DeFanti, T.A., Kenyon, R.V., and Hart, J.C., 1992). Jaron Lanier popularized the term “virtual reality” in 1987 (Crecente, 2016; “Who Coined the Term”, 2016). The Sensorama, an interactive multimedia theater experience, was invented in 1957 by Morton Heilig (Rheingold, 1991). Stereoscopes have been in use since the Renaissance. These technologies already have a long history. And representations and illusions to communicate ideas and imagination have existed since the dawn of humankind.

It is only recently that the convergence of digital software and hardware technologies and computational power allowed for cost declines to make the technologies for immersive realities possible for mass consumption. Even just 4-5 years ago, the costs of an HMD was approximately $40,000 or more. Today the cost of an Oculus Rift HMD is under $500. These new demands and opportunities for VR, AR, and XR have caused rapid advancement providing for a new understanding of being in reality and other immersive realities.

Recent developments in these emerging technologies are revealing the capacity to redefine established understandings of presence and awareness. Through the previously discussed learning theories, they provide a new pathway to influence creative thinking, empathy, and ethics. By looking at how these emerging capacities work through recognized philosophical and physiological linkages, including perception, phenomenology, embodiment, and neurology, it is possible to gain insights into the potential these combined concepts have to impact creative thinking, empathy, ethics and understanding, ultimately solving the challenges and dilemmas in all realities capturing time and attention in today’s and tomorrow’s societies.

Congruence

Rules and theories that apply in reality can apply in and impact VR and even be extended past the rules in reality. And conversely, what is experienced in VR can often apply and impact the understanding of reality (Westervelt, 2015). The Virtual Reality Human Interaction Laboratory (VHIL) calls this condition “coherence” or the “quality of being logical and consistent.” But with a geometrical definition of “identical in form” and in use as an adjective, “in agreement.” Congruence adds to the discourse describing the physiological relationship between reality and the new realities such as VR, AR, and XR. This becomes even clearer when considering the

opposite conditions of each word. “Incoherence” means “the quality of being illogical, inconsistent, or unclear.” Where as “incongruous” means “not in harmony with the surroundings or other aspects,” or as its Latin origin describes, “not in agreement.” The concept of congruence allows for an understanding of both the equal potentials between reality and new realities while recognizing differences, but not in just a negative connotation as incoherence implies. This is a critical difference, because when an individual can recognize that reality, or congruent new reality, context, or extended (incongruous) experience as a “diversified experience” (Ritter, et al., 2012), that awareness can precipitate cognitive flexibility.

In this 2012 study by Ritter et al, researchers proposed that “diversifying” and active involvement conditions would prompt cognitive flexibility, or creative cognitive processing. Researchers presented individuals with complex unusual and unexpected events in virtual reality. This experiment and a similar one showed increases in cognitive flexibility over control groups.

Congruency, in this paper, aligns well with the “diversifying” conditions described in the study, especially when unusual and unexpected events are introduced. This works with the idea of incongruent or not in agreement. This study proves to be an even richer resource as congruency with virtual reality is one of the base control combinations used to increase cognitive flexibility.

Phenomenology and Perception

Alberto Pérez-Gómez, a noted architectural scholar with numerous articles and texts on phenomenology, makes a case for the inseparability of time and space from a phenomenological perspective, arguing for a perception that involves all senses in a unified whole. His assertion that “meaning is not something merely constructed in the brain” but that it “is given in our normal, bodily engagement with things, things that we recognize [...] instantly as the embodiment of an idea, word, or category resonates potentially with both the physically and the digitally constructed world surrounding us.” (Pérez-Gómez, 2012) He also provides the logic for a vision of a learning experience through the emerging technologies of VR, AR, and XR. He even describes how in the awareness of that immediacy of perception “reside both the possibilities and the limitations of digitally generated images as potentially contributing, as a form of architecture, to a meaningful lived environment.” (Pérez-Gómez, 2012) These mature concepts, built on decades of phenomenology debate around the flattening and de-valuing of an

architectural environment, and in part a critic of traditional architectural representation and their resultant realities, expose a rich topography where whole body, time and space, and phenomenological perspective support a philosophy for congruent learning experiences.

Phenomenology and neurology are also converging into a shared discipline called neurophenomenology. This is a milestone in pulling together emerging knowledge from both the cognitive sciences and phenomenology.

Embodiment and Disembodiment

Harry F. Mallgrave researched the concept of embodiment, which is closely intertwined to the phenomenological perspective, to an early origin through his 1994 text and translation with Eleftherios Ikonomou titled *Empathy, Form and Space: Problems in German Aesthetics*, 1873-1893. One of the translated and principal authors was Robert Vischer. One of the earlier contributors to the discussion and development of embodiment and phenomenology, Robert Vischer wrote a text in 1873 and published in Germany entitled *On the Optical Sense of Form: A Contribution to Aesthetics*. He works with the sensory and motor systems together describing it as emphatic sensation, in which the whole body is stimulated and consciously involved. This might be described as an active self-awareness in context. Vischer suggests emphatic sensation can strengthen a vital sensation, which could also be described as a deeper, whole body conscious and memorable experience. And he also connects this to not only a dual sensory and motor experience, but also to a mental picture or activity and particularly imagination and imagined experience—even in analogy with the perceived and real surrounding context. Vischer reinforces the deeper experience describing the sensation as both “enlarged and deepened” by this integral body experience. Even further, he states, “an objective but accidentally experienced phenomenon always provokes a related idea of the self in sensory or motor form. It does not matter whether the object is imagined or actually perceived; as soon as our idea of the self is projected into it, it always becomes an imagined object: an appearance.” Something he describes the potential as, “kinetic, volitional, empathetic sensation” (Ikonomou, E., & Mallgrave, H. F. 1993).

In this perspective, embodiment can be seen as a key connector to the experiential and similar learning perspectives and phenomenology perspectives in addition to describing these dual motor systems as emphatic sensations. It ties in mental and imaginary experiences as if

congruent, and finally even imbues these conditions with volition (one's will or self agency) and empathic sensation (empathy).

Disembodiment presents a different set of opportunities which do not oppose the idea of embodiment, but further advances opportunities of an understanding of self. Specifically an understanding outside of one's self. In observations of students experiencing immersive VR headsets, the students will often reach their hands up in front of their faces and say, "I don't have any hands." This observation continues with the rest of their body missing and the realization that they are essentially having an out-of-body experience. This engenders an awareness of another perspective: a perspective that is a unique and shifted reference from their own reality but one that is congruent in terms of experiential and spatial qualities.

This shifted reference can produce a new awareness in two notable conditions: (1) In terms of understanding concrete reality, the observer sees a convincing alternate view that can be similarly concrete, but from another's perspective and one they recognize as not their own due to their perceived disembodiment. (2) The convincing alternate view can supplant a known reality and produce a more abstract perspective while maintaining the congruent experiential and spatial qualities. This might also be similar quality to the "diversifying" condition and cognitive flexibility researched in the Ritter et al. (2012) study. The disembodiment in this second condition allows an escape from known concrete limitations such as gravity, physics or even time to see in an entirely new way not possible in reality. The result may be improved imagination or creativity, again similar to the Ritter et al. (2012) study.

Presence, Awareness, Perspective and Neuroscience

Presence is an internal psychological state and a form of visceral communication (Jerald, 2016). It complements a similar technical term often used in virtual reality technology called immersion which is an objective level of sensory fidelity (Jerald, 2016; Berg, Vance, 2016). Presence closely resembles embodiment as described in the previous section more than the technical description of immersion. Presence closely resembles Robert Vischer's emphatic sensations. Presence is the subjective visceral and psychological understanding of being or sense of someone's immediate environment or situation. This might be one's own perspective or view into a situation, context or content and can also be thought of as a deeper level of situational awareness. This can be real, mixed, imagined or virtual.

Awareness in relationship to perspective or typology of view is also an important aspect of understanding which has advanced through emerging technologies. Years ago a first-person view would have been a perspective drawing representative of that person's viewpoint. The horizontal field-of-view (FOV) was adjustable with exteriors often drawn at 60º or less and interiors drawn at wider angles. First-person games are often set to 90º or wider. Both of these are subjective and set either by understanding the natural perspective of the viewer through the screen or what looks appropriate on the paper depending on size and subject matter being communicated. Today, the term "first-person view" better describes the view a fully immersed individual experiences in virtual reality where the technical conditions are set to as wide as a FOV as possible and natural vision is replicated through stereoscopic viewing through a headset or on large-screens surrounding the viewer. When technically correct, this can lead to a strong level of presence for the individual in virtual reality and one that aims to replicate typical sensory input in reality. Providing an individual with this perspective is very powerful in terms that Mallgrave and Vischer both delineate as described above. This sense of first-person presence also directly supports the educational learning theories described in Chapter 2 including Constructivism, Experiential Learning and Situational Learning Theory.

This perspective can be shifted and experienced from the technically correct immersive first-person viewpoint to a second-person viewpoint, third-person, or even an intentionally artificial and arbitrary viewpoint.

In some current large-screen virtual reality systems, one individual is provided first-person view through head-tracking to adjust to the viewer's position and direction of view. Additional viewers see what the first-person is looking at and can literally be conceived as a second-person view. This condition mirrors literary narration with the first person sharing their view to the additional viewers. "You can see exactly what I see," the first person viewer can say. Pre-recorded 360º video is also an immersive medium where this second-person viewpoint becomes valuable for communicating ideas and intent.

A third-person view is another opportunity for adjusting viewpoint. This is often a gaming perspective where the camera follows closely behind and above the primary character whose movement is directed by the viewer or player. This viewpoint provides a view around the primary character and wider FOV than a typical first-person view. One advantage this viewpoint

provides is an awareness of the viewer's character in context and a unique sense of self where the viewer can see themselves in the character externally.

These viewpoints also align with spatial navigational viewpoints called procedural or "ego" and survey or "exo" (Thorndyke, Hayes-Roth, 1982). Procedural knowledge is route-based knowledge or a way to understand movement from one's own direct movement and subjective perspective. This is another way to see how a view of a context preferences a particular world view to one's own. Survey knowledge combines disparate locations as if viewed on a map with an understanding of those relationships and hierarchies in a more objective and external manner. These spatial navigational viewpoints also open the possibility that being able to mix these viewpoints from ego to exo allow for a more complex understanding of a context and situation.

Even further, research has shown that human perception has the capacity to adapt to arbitrary conditions. It has been shown that the traditional human FOV of horizontal 180º can be successfully manipulated and adapted to a 360º horizontal FOV where the wider FOV is compressed onto a traditional HMD. This extended FOV is described as an augmented human capacity (Ardouin, et. al. 2012). Another DIY research hack provided a system that shifted a first-person VR HMD experience to a third-person view of themselves (mepi.pl, 2014).

Peripheral vision and proprioception also have important implications in this context. Given that a traditional human FOV is 180º, and the central field of vision is approximately 5º, much of the understanding of the world, details and conditions fall into peripheral view. The main functions are recall and recognition without focus, identification of forms and movements known through Gestalt Psychology, and kinesthetic sensations about the context and background of the detailed visual perceptions or focus. Peripheral vision puts us in the world and communicates inside and outside conditions and depth by providing the environmental context and cues to complete a sense of presence.

Likewise, proprioception contributes as an additional layer of kinesthetic sensation. On top of the primary senses, proprioception or kinesthetic awareness are full body mechanosensory abilities, described as part of additional sensory modalities that add to a stronger sense of presence and awareness.

Jeff Hawkins and Sandra Blakeslee in the 2007 book, *On Intelligence*, advance these ideas of senses and perception through neuroscience—literally the neo-cortex: Being is tied together through connections between doing (motor cortex) and sensing (somatosensory cortex being its adjacent complement) based within a mental construction of our physical world stating, "perception and behavior are almost one and the same." This is also a contemporary and neurological restatement of the early embodiment work previously mentioned by Robert Vischer earlier in this chapter. Hawkins and Blakeslee also make an intriguing statement supportive of the idea of congruence, "The cortex's hierarchical structure stores a model of the hierarchical structure of the real world." This points to the mind's ability to be the bridge between real space and other realities—and in particular that the ones most easily acclimated would be the ones sharing the structure of the real world.

Even recently, the concept of mirror neurons have come to the notice of the neurological discipline. Mirror neurons in animals have shown that the same areas in the brain involved in a motor activity are also fired when observing the same activity. These connections are being studied in humans to understand the impact on empathy and ethics (Keysers, 2011).

And current neurological work on perception, mechanosensory, the neo and motor cortex, and mirror neurons all interweave supporting phenomenology, even neurophenomenology toward congruence, empathy and ethics. A closer look at some of this work and the relationship to empathy and ethics and problem solving is in the next section of Chapter 3.

Empathy, Ethics and Problem Solving

Elisabeth A. Sutherland, in her 2015 Masters of Comparative Media/Writing thesis entitled "Staged Empathy: Empathy and Visual Perception in Virtual Reality" at MIT, also discusses mirror neurons as related to empathy in terms of reflexivity where "a temporary estrangement from the bounded mental self that allows a viewer to reflect on their embodied self as an instrument of perception." Sutherland also discusses a concept of "intentional looking" where "intentional" in VR specifies a conscious lens providing a resonance between our bodies and the environment or subject of the intentional looking. Sutherland defines staged empathy as a "process of empathizing with the experience of another where some aspects of the inner simulation of empathy are performed within a virtual space" (Sutherland, 2015).

The Stanford Virtual Human Interaction Lab (VHIL) has done some of the most focused and current work on VR, AR, XR and empathy (Empathy/Diversity, n.d.). VHIL has several studies showing the impacts of a virtual experience on empathy. One 2016 research study showed that an immersive virtual environment can impact empathy for the elderly more than traditional mental simulation (Oh, Bailenson, Weisz, & Zaki, 2016). Another article covering the work VHIL was presenting to Congress in Washington, D.C. in 2016 showed the potential impact VR might have to communicate a homeless individual's experience (Cimons, 2016).

Chris Milk presented VR as an "Ultimate Empathy Machine" in his 2015 TED talk (Milk, 2015). This helped to set the stage for several works being presented at Tribeca in 2017, and not without controversy (Robertson, 2017). What seems clear is that the rapid technological development and implementation by artists and filmmakers does need to be balanced by a reasonable critical expectation of the technical work and capacity that is being developed at VHIL and elsewhere. These emerging technologies advance but not always in parity to some of the special effects and visual fidelity that often appear in the film industry.

A connection between VR and empathy has been shown, and the details will continue to emerge moving forward with scrutiny and awareness of this connection. The impact of VR, AR, and XR on ethics also needs to be studied and a discussion on ethics and the potential implications is included next.

A general and well established ethics framework useful to this discussion can be summarized through Lawrence Kohlberg's stages of moral development. These stages were built upon the cognitive development work by Piaget (Piaget, 1932). Kohlberg initially developed this framework in 1958 and continued to develop it throughout this career. There are three levels and two "stages" to each "level" which include: Pre-conventional Morality, Conventional Morality and Post-conventional Morality. The first two stages as part of the Pre-conventional level, (1) Punishment, Avoidance, and Obedience and (2) Exchange of Favors, generally appear in primary education but can also manifest into middle school and even high school years. The next two stages as part of second level Conventional Morality are, (3) Good boy/girl and (4) Law and Order. These middle two stages are seen in upper elementary, middle school and high school, with stage (4) not typically appearing until high school. The last two stages, (5) Social Contract and (6) Universal Ethical Principle Driven are usually not seen before college and stage (6) is rare even in adults. (McDevitt, Ormrod, 2010)

Given the progression of learning theories presented beside 21st Century Skills, UDL, and Bloom's Taxonomy (rev), providing a transformational experience that embeds congruency and reframes perspective, presence, and awareness may provide an ethical movement up in Kohlberg's stages of moral development. For instance, to enhance the desired personal skillset of a 21st Century learner in these times of dramatic change, it would appear desirable to ensure graduates from high school have at least developed to stages (3), (4) or (5) rather than (2), (3), and hoping for (4).

Matthew B. Crawford adds significantly in this part of the discussion with his two books *Shop Class as Soulcraft: An Inquiry into the Value of Work* (2009) and *The World Beyond Your Head: On Becoming an Individual in the Age of Distraction* (2015). Both books pointedly and philosophically address topics on embodiment and ethics with a critical look at 20th Century industrial tendencies as described earlier in this paper's introduction, and with a recognition of the whole body in work, learning and ethics. He covers issues of agency and empathy in this light going as far as incorporating cognitive extension as: "an unmediated sense of the tool extending the body" and embodied perception as: "possibility of movement" and "way of acting". This part of Crawford's analysis and work was built upon by psychologists James A. Gibson in his 1979 text *Ecological Approach to Visual Perception* (Gibson, 1979) and Lawrence Shapiro in his 2011 book *Embodied Cognition* (Shapiro, 2011). Crawford further expands upon this work looking to Rodney Brooks' 1991 paper, *Intelligence without Representation* where, "The task of solving problems needn't be accomplished solely by the brain, but can be distributed among the brain and the body and the world" (Brooks, 1991). This model of triangulated accommodation recognizes the importance of previously mentioned learning theories in this paper in addition to the congruent importance of VR, AR, and XR in Crawford's argument. Crawford continues this theme describing individuality as both concrete "conflicts and cooperation" (Crawford, 2015) with other people while earning an "earned independence of judgement" (Crawford, 2015) that closely resembles the mid to higher order ethical reasoning by Kohlberg. Crawford also discusses a concept he terms "Intentional Commons" where individuals share in an "actual shared experience" and "common enterprise" through the triangulated accommodation for a co-presence with natural scale—even something he specifically recognizes as a 3rd person concrete perspective (Crawford, 2015). Crawford's work scaffolds to a recognition of a missing link toward an ethical framework that eluded learners within the 20th Century framework of a

monolithic learning experience described by Christensen and one that is again recognizable, desirable, achievable and enabled through deliberate as well as congruent means.

Like empathy, ethics can shift through congruency with an awareness that the inherent impact of these toolsets are capable of a sense of presence, awareness and lasting psychological effects with both positive and negative consequences. It also stands that usage needs close accountability in particular with the exposure to youth. Initial work is being done in parallel with the rapid development of these congruent toolsets, but consideration must be in the forefront to apply and implement these ideas and toolsets responsibly and deliberately (Madary, M., and Metzinger, T., 2016) This broader context on ethics is intentionally presented for discussion and awareness to youth, not just in knowledge, but also in active responsiveness and agency for the potential impact today's youth can have on the ethical decisions and implications of these emerging toolsets. This fits well within the 21st Century skillset accountability and responsibility.

As the focus on core STEM skills continues and even tightens, these ideas of the importance of empathy and ethics are more important (Berkowicz, Myers, 2017; Zakaria, 2015). And here again, the deeper learning theories and congruence play an important role and even one beginning to be recognized in STEM research and academic advancement. A 2015 American Society of Engineering Education research study proposed empathy and the method "empathic walkthough" as a key characteristic for a successful engineer. This was even articulated in terms of "perspective-taking" to "better understand the complexity of underlying socio-technical system of use" (Gray, Yilmaz, Daly, Seifert, and Gonzalez, 2015) This is central to and originates from human-centered design and intersects directly with design thinking (Kelley, 2002).

Recalling Robert Vischer's discussion on the concepts of embodiment and phenomenology, he also directly connects them to empathy and even abductive reasoning. He connects the emphatic sensations to immediate and responsive feelings, or empathy within the imagined experience, and then ascribes "the association of ideas" as the empathetic sensation stimulates connections to other experiences, real or otherwise. Even, "Here, empathy is asserting itself within the association of ideas." (Mallgrave, 1994)

John Kolko, an established expert in design thinking, also articulates design thinking around a model of reasoning which is generally accepted and one that can be compared to the Kohlberg

model in that it could be tiered or leveled in a similar way as an elevated form of reasoning. An empathic walkthrough and perspective-taking are key to successful engineering. This articulated model of reasoning also supports the empathy, ethics and congruence schema of this paper.

Kolko begins by reviewing deductive reasoning as “an argument that guarantees the truth of the conclusion,” inductive reasoning as “an argument that offers sound evidence that something might be true” and based on experience, and then abductive reasoning as “the argument to the best explanation” based on observed phenomena and prior experience (Kolko, 2010).

Kolko then posits that design synthesis is abductive reasoning in a design process and where synthesis is an abductive sensemaking process. Kolko defines sensemaking as, “action oriented process that people automatically go through in order to integrate experiences into their understanding of the world around them” (Kolko, 2010). So sensemaking already contributes to a moment of congruence in the context of this paper. Kolko then addresses design synthesis as a process of externalization and creation where a process of spatialization occurs allowing the designer a mental model of the design space” (Kolko, 2010). Interestingly, Kolko describes the process like this: “taking the data out of the cognitive realm (the head), removing it from the digital realm (the computer), and making it tangible in the physical realm in one cohesive visual structure (the wall), the designer is freed of the natural memory limitations of the brain and the artificial limitations of technology” (Kolko, 2010). In 2010, HMDs were not available in university design studios. Today they are beginning to appear. This is good description of a congruent process possible today that may not have been envisioned within the limitations of 2010. And the process holds up as a critique of technology that existed in 2010 and supports a congruent proposal of the process in 2017.

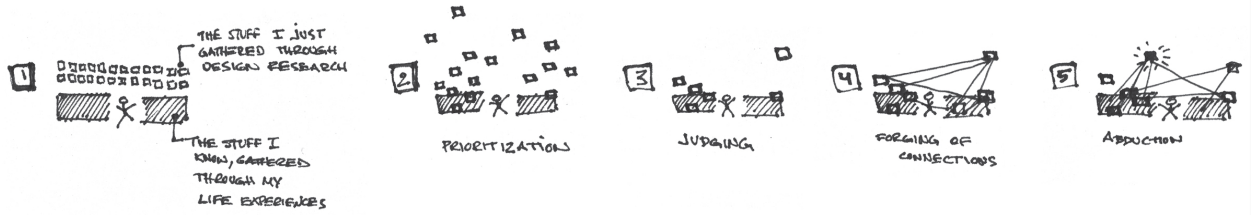

FIGURE 2 Kolko’s Synthesis Process
From Kolko, 2010

Kolko also discusses specific actions a designer takes during synthesis. They are (1) prioritizing, (2) judging and (3) forging connections (See Figure). These become the fundamental steps in abductive thinking. While Kolko concedes the process may not be linear or

clean, he also promotes three design methods which emphasize the fundamental steps in abductive thinking and suggests “they can be applied in design problems of any discipline or subject matter” (Kolko, 2010). It is this assertion that abductive thinking can be applied becomes a strong forward focal point for the broader direction engineering and STEM education to go and may be going (Gray, Yilmaz, Daly, Seifert, and Gonzalez, 2015) and again supporting the empathy, ethics and congruence schema of this paper.

CHAPTER 4 CONVERGENT DIVERGENT TOOLSETS

CHAPTER 4 Summary

There are emerging hardware toolsets providing the opportunity to directly leverage the learning theories and congruent learning environments. These are the ones that incorporate advanced visualization with VR, AR, and XR in particular for digital prototyping via CAD and then CAM and CNC for real prototyping. Prototyping is also a phenomena embedded in multiple design models that are increasingly important in professional domains in addition to several academic disciplines. In applied settings, they fuse STEM learning and design thinking through new opportunities for making, envisioning and communicating ideas. The current emerging toolsets add to existing tools in a complementary way producing new personal knowledge previously only acquired in limited real world settings and often not possible at all. They provide the opportunity for a new stage of design with data and parametrics that form a new layer of fundamental knowledge construction through virtual machine manipulation and visual scripting in the creation a new human-centered design in the loop. This will provide the elevation of digital craft to a new form of CNC: HNC or Human-centered-design-in-the-loop Numeric Control. And this will be in an environment more conducive to an individual digital craft, a made-to-order solution, mass customization (Kieran, S., & Timberlake, J., 2004), or a bespoke way to SEE and MAKE.

Digital to Real Prototyping

While many prototyping technologies have been around for decades, it is only recently that the cost, usability and convergence of technologies have approached a level that prosumers and consumers are beginning to access for their potentials. This general access is critical for adoption and change to occur in educational, professional and industrial applications. With general access providing easier access, experience, and informal tinkering, these technologies can gain the momentum for new industries and practices to take root in addition to advances into new academic implementations and advances.

In the academy, 3D printing has taken root particularly due to the cost and ease of integration. It has allowed rapid physical prototypes from CAD directly from many software platforms. Academic institutions have quickly adopted these desktop tools into engineering and design courses. These tools are often found in both monitored labs and in student accessible studios and workspaces. As with several CNC technologies, 3D printing also scales with process,

material, and physical size demands. The lower cost solutions such as desktop fused deposition modeling are more prevalent in labs and studios where students have access to operating the machines and printing their own designs in a variety of thermoplastic filaments. Higher cost additive manufacturing solutions such as Stereolithography (SLA) and Selective Laser Sintering allow for additional material and size options but these machines are not as accessible to direct student use and are usually restricted to lab monitors or staff.

Additional inroads have been occurring with CNC lasers, lathes, and 2-3D routers. These tools have been harder to integrate for direct student use at the same scale as 3D printing due to a bigger separation in direct software integration where some scripting and coding is often required and due to cost and infrastructure. The machines are more industrial in the sense that they are much messier and require more environmental system controls due to material dust and even fire hazards. Developments to adapt these technologies to a desktop level and cost structure are improving quickly. Some smaller systems utilize open illustration formats such as Scaled Vector Graphic (SVG) and even Adobe Illustrator itself for both creation and then fabrication through these tools.

At the highest end of CAM, Tesla Factory in the automotive domain provides a good example of the state of the art design and production in CAM and CNC in California. It is largely automated with over 160 specialist robots including 10 of the largest in the world (Wired, 2013), the facility and process complement a perpetual evolution in process where technologies and automation are being continuously reviewed with design and manufacturing collaborating on every step. The Tesla Factory defines mass customization with the high level of production and automation while each vehicle is custom made-to-order.

Robots and higher degree CNC mills are arriving in the academic environment usually through grants or larger external support as the cost and infrastructure requirements and knowledge requirements are more restrictive. This type of equipment is often in a closed lab environment with few individuals directly accessing the technology. However, common formats and direct links to design software output are also changing the accessibility of these high-end CAM technologies and the cost is attainable (Tested, 2016). And the interface to create the machine code is built straight into a partnered 3D design and manufacturing software called Autodesk Fusion 360. And STL and OBJ formats are being used as one common format that provide a

more universal access to these CAM technologies. The STL is one of the most universal formats used as the basis for 3D printing.

MX3D (MX3D, 2017), partnered with Joris Laarman Lab (Joris Laarman, 2017), is an example of the early and advanced work being produced in this area. It combines 3D additive manufacturing and robotics with an intention toward a new craft of design and local production that involves computational design. Initial projects include the Dragon Bench, ARC Bicycle, Maker Chairs and Butterfly Screen. This work includes advanced parametric design and includes resins and different metal alloys in the actual fabrications.

FIGURE 3 - Work by MX3D / Joris Laarman
From Joris Laarman and MX3D, 2017

Digital prototyping, in addition to the real prototyping capacities discussed above, has been increasing for the past few decades with the growing capability of computer hardware and software. Increasingly, the ability to digitally model a design and its context has shifted ideas of representing a design to simulating a design. These models, through more sophisticated networking, are also advancing collaborative work across disciplines and providing a more natural accessibility to communicating ideas in more visible ways to consultants, clients, and even the public. Some of the simulations that are professionally and academically accessible include structural, flow, lighting, fabrication, construction, energy and material analysis. The digital models can also be used for advanced prototyping, advanced visualization and documentation.

Integrated Project Delivery (IPD) from the Architecture Engineering Construction (AEC) domain also puts this digital model as the persistent conceptual focus of the project, shifting even the contractual focus of the work to the project itself rather than a legally self-protective priority and method of work from the 20th century model. This project delivery model lends itself better to a

model-centric and project centric focus which aligns closer in terms of a human-centered design approach where the project is not owned by any one constituent, but instead with a shared structured risk and value-system by all constituents.

Digital prototypes bring forward a method for design development and understanding earlier in a project process where critical decisions are often made. And these decisions can be made in and around digital prototypes without the cost and time yet invested in physical mock-ups or prototypes. In this way, rapid prototyping can be even better supported.

Shifting these digital prototyping technologies and processes into a congruent reality as VR, AR, and XR is also already starting to occur. A software for sculpting in VR with output in a common export format is already possible today. Oculus Medium will export a VR design in OBJ format for use in both interactive visualization and simulation or CAM software for real prototypes (Unimersiv, 2017). MakeVR, a more CAD-like software than Oculus Medium and made by Sixense, will also export STL files for 3D CAM prototyping (MakeVR, 2017). It is also based on the 3D ACIS geometric modeling kernel which many more traditional CAD softwares use for sophisticated designs. These newer VR softwares leverage the user's full body interaction past a traditional Graphic User-Interface (GUI) into what is being described as a Natural User Interface (NUI).

Makerspaces and Seeing Spaces

Makerspaces have been a growing culture since before 2006 when the first formal events started to occur around the world. Originating from a "Hackerspace" in 1995 called "C Base" in Germany, the concept quickly spread and morphed to a more open makerspace. This space engendered entrepreneurs, community learning and hands-on collaboration around making. TechShop and Fab Labs were both expansions on the maker movement and the latter included mobility for the first time to support its network of growing locations. The impact of the maker movement continues to school makerspaces and even makerspaces in public libraries for community accessibility. It should also be noted that as this maker movement expanded, it was likely also a reaction to a time in education where industrial tech and shop classes were being phased out of schools.

Bret Victor, a renowned UI designer and founding member of Apple's future-interface prototyping team, produced the concept "Seeing Spaces" in 2014 that expanded on the ideas of

the maker movement to include advanced visualization and dynamic simulation. From the perspective of a computer engineer and UI designer, Victor conceived a space that provided a unique understanding of design and prototyping. An individual could build a prototype of a smart widget, something with sensors and electronics, which could be measured by video and computer with physical input and digital input through sliders to grasp as holistic of a picture around the prototype as possible during prototyping. In the same sense as a makerspace, he also envisioned this "seeing space" to serve a continuum of learners from informal tinkerers, professional engineers and then pure science. The following figure shows this model with text above for a more design oriented model in the same structure.

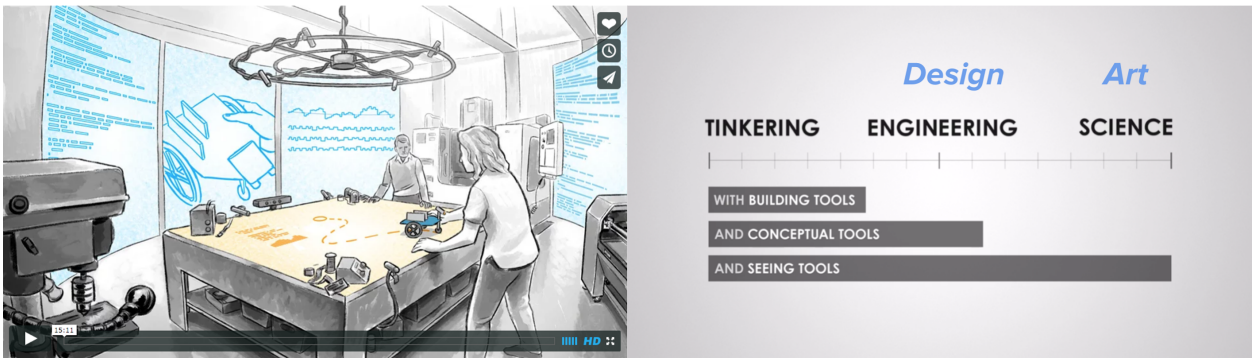

FIGURE 4 Bret Victor Seeing Space Scaffolding
From Victor, 2014

Victor then built on "*Seeing Spaces*" for his next chapter published at the end of 2014 entitled, "*The Humane Representation of Thought*." He picks up the active making mantle into a full criticism of static media of the past to propose a dynamic medium more appropriate of knowledge work that leverages the range of human capability. He specifically includes references to Gardner's intelligences and even Gibson's ecological work on visual perception and embodied cognition. This critic on static media could also harken to a factory based education where books, one of the static media mentioned, were a basis for the classroom work and structure for a full and formal curriculum for all students in the room. And his response with the dynamic media also recognizes the potential of VR, AR, and XR for what he describes as "dynamic conversations" for a "physical intuition" with direct manipulation in a "sketchy and improvisational mode." He continues the dynamic media to support a thought process externally and to create new knowledge. Describing this dynamic material process, he defines a duality between objects and environments, seeing two "form factors," one to "hold and inspect from the outside," and "other representations that you want to be embedded in, to explore from the

inside." Victor also suggests that the physicalness of tools for thinking have disappeared with screen tools. He suggests that the dynamic medium trumps the real tools, but that there is a need to get the computational and dynamic material out of the screen into the world for "tangible" representations to again work on with hands and bodies.

From this vantage, it's clear to see the potential Victor recognizes in a dynamic media to see and make. And he begins to articulate this loosely referencing embodied and tangible contexts, like VR, AR, and XR. This even better describes congruence and its potential. This becomes a new baseline for seeing and making based on an individual's situated context, for an individual condition or situation that may be real, imagined or digital, with both the individual working with any number of digital or real CNC, for the purposes of human-centered design.

Bespoke CNC to HNC

As Victor notes, a dynamic media as he envisions puts the media back to a tangible and embodied media. The situation is also a bespoke situation, where the individual is potentially both within and outside of the situation. With human-centered design, not only is the focal point the people being designed for, but they and the designer can both be embedded in the design condition, one that is literal or abstract or one that tests different ideas and allows a space for creative thinking, abductive reasoning in a "sketchy and improvisational mode" as Victor described. And this model, a creative digital prototype with both human-in-the-loop and human-centered design mutually focusing the project goals, can then be given physical substance as specifically required through direct bespoke CNC where the tangible and embodied media can directly be translated through cognitive extension. This is a direct human-centered and human-in-the-loop numeric control, echoing an earlier hand craft.

CHAPTER 5 FORWARD LEARNING EXPERIENCE

CHAPTER 5 Summary

The Forward Learning Experience was envisioned and created in the Iowa State Industrial Design Department in the summer of 2014 as a mobile design technology and learning platform to deliver STEM, 21st Century Skills, and Design Thinking to constituents across the State of Iowa. It was a partnership of the Iowa State University College of Design, College of Engineering and Extension and Outreach. Its primary audience has been K-12 in schools and other related venues such as STEM, Science and Maker fairs, Science Centers and 4-H venues. As of July 2017, It has reached almost 45,000 constituents in 175 sessions.

FIGURE 5 PHOTOS OF THE FLEx
From the author

Description

In a Forward Learning Experience, there are generally two types of experiential learning and tools. These experiences and tools overlap in concept and all actively engage the participants individually and directly. The two types of experiences and tools encompass the ideas of “SEE” and “MAKE”. These experiences are also described as “visualization” and “fabrication” in design technology education and at the professional level. These two focal points also parallel ideas of

“digital prototyping” and “real prototyping” which is also part of STEM, iterative thinking in design and support the ideas of a real to virtual congruence.

SEE tools involve advanced ways of seeing to include VR, AR, and XR. AR involves ways of incorporating digital information into the real world. Virtual reality allows participants an alternate immersive computer-simulated world that replicates a sensory experience. In a sense (seeing), through the mediums of AR and VR, ideas can be conveyed and experienced in new ways. It is now possible to see what someone else’s perspective is—literally. It is possible to compare and experience iterations of ideas that are not real to ones that are virtual or augmented. This can be done alone or in collaboration with others depending on the type of technology combined with the project and team goals. It can allow a very direct and open communication—a shared vision of expert ideas to groups of non-experts for better co-creation and understanding without misinterpretations of representations or translations.

This new set of SEE tools also allows for access into the foundation of the technology through an immersive experience. Physical circuit bending allows for users to get an understanding of programming and electronics through physical sets of modules such as Little Bits or Snap Circuits. Osmo and Lego Mindstorms take this further by intermixing physical steps with digital ones with results being visible both ways (digital and physical). VR provides an even richer environment to program with modular blocks in a similar way to visual scripting and is exemplified through a 2016 application for the Oculus and Vive called “SoundStage.” Preset instruments can be played in VR or custom ones can be built from the ground up through visual scripting. In a way that combines the visual scripting logic of Rhino Grasshopper and modular sliders and seamless interface of Apple Garageband, this new experiential scripting yields a musically creative sandbox—a new way to build sound, experience and share it. Eventually, this new way to SEE will connect every foundational scripting medium with new digitally creative and learning opportunities in visually (and acoustically) experiential processes and products.

This is a place where understanding the formalizing nature of the Internet of Things (IoT) in terms of its basic structure is possible to experience and manipulate in virtual reality as if real. This gives the user a sense of presence at the roots (and on up) of this new paradigm in appropriate embodied learning tools.

A MAKE toolset presumes a more physical space of consequence with machines or place. This isn't necessarily required and likely better understood digitally through virtual reality first in a digital prototyping mode.

This critical overlap can not be articulated enough. Intermixing these concepts of SEE and MAKE become even richer ground for learning and creating.

For instance, seeing a 3D printer work can be a valuable direct experience to understand the differences in materials and types of 3D printing technologies. It also helps to see the translation of the digital model idea as a design file to a more machine language file for printing—actually seeing the graphic preview of the printed layers going to a Fused Deposition Modeling (FDM) printer and seeing the printer follow the same CNC commands helps to understand the connection to CNC and the "direct" numeric control of a machine. This can be further extended when considering telepresence and robotics that are both emerging skills and tools in the marketplace.

Being able to manipulate physical electronics modules continues this idea of interacting with machines. Again Little Bits, OSMO or Snap Circuits or other physical circuit bending technologies provide a physical experience to translate ideas through technology with tangible and sensory-rich results.

These mixed physical-virtual experiences are also powerful for users as it places them in control of interaction using their body to see things that don't physically exist and share that experience with a group of peers. These new mixed realities are proven to engender creativity (Ritter, et al., 2012) and need to be in the hands of future generations.

Importantly, these new technologies are already showing up in the professional design and engineering professions. Today, to show a client, contractor or consultant the design intent by moving through the project freely and interrogating the design for many attributes such as a Building Information Model (BIM) project provides - both the materially rich visuals in addition to the essential data - requires much less equipment, investment and expertise than even 5-10 years ago. In addition to realizing complex forms, advances are also happening through construction, fabrication and even to the operations of facilities where the transfer of documents

is now object oriented database and real-time. This is an example of creating new value, opportunities and deliverables for the professions and stakeholders.

A case study presented at Autodesk University in December 2015 by Airbus, APWorks and a generative design team from Autodesk called “The Living” presented a “bionic partition” that was designed through algorithms optimizing a micro-lattice structure and that was run through thousands of constrained variations and ultimately produced in an additive manufacturing process. This amalgam of micro-manufactured parts even required a new metal alloy called Scalmalloy for 3d printing for first/final prototype/production runs.

Experiences, Realities, and Forward

As of July 2017, FLEx has delivered approximately 175 sessions both on campus and around the state of Iowa and has reached almost 45,000 constituents, most of whom are students. The number of sessions have continued to increase each year, with 2017 poised to exceed 2016’s previously record total. Notable sessions and locations include the Iowa State Fair, 4-H, Women in Science and Engineering (WiSE), Precollegiate Programs for Talented and Gifted, Upward Bound, and Science Bound.

Sessions begin with a short 10-15 minute presentation on design thinking, STEM, 21st Century Skills, The Universal Constructs to specifically include the 4C’s, and the possibilities of advanced and emerging technology. Students are asked what they think Industrial Designers do, and are then given examples of things this profession may have been designed (such as cars, airplanes, chairs, tools, etc.) These concrete, everyday, familiar examples help to put the students at ease and broaden their thinking and range of possibilities from just “art.” The presentation also emphasizes how young people will likely be expected to interact with tools that are considered cutting-edge today (VR & AR) as part of their routine professional lives in the near future. The sooner students can be exposed to a real life, physical example of emerging technology and see the implications and applications, the better. Technology will be much more advanced when students enter the workforce in 5-15 years, but getting a baseline and early feel for the tools will help them adjust, be flexible and adapt to whatever is coming in the future.

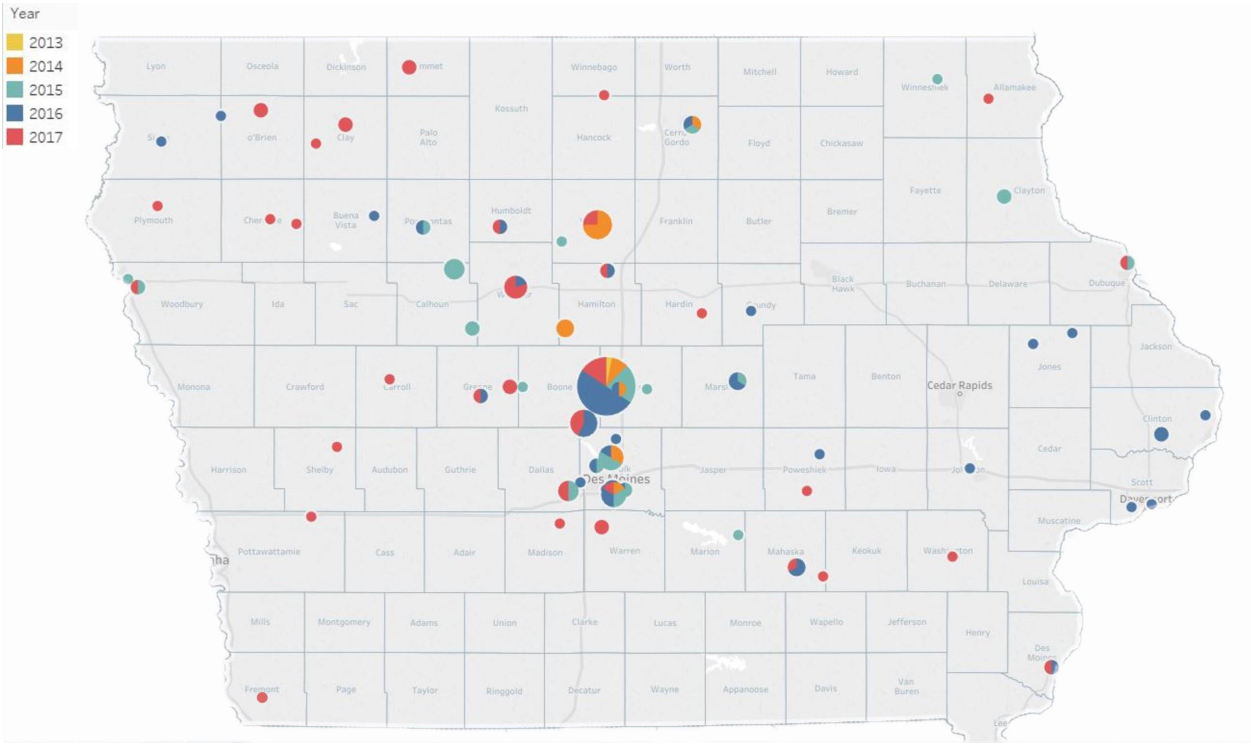

FIGURE 6 FLEx in Iowa 2013-July 2017
Provided by author

The presentation concludes with a short description and walkthrough of each station of technology the FLEx provides, and then the students break into small groups of 5-7 and explore each station collaboratively; groups rotate after 10-15 minutes. This ensures each student has exposure and experience with each piece of design technology. Faculty members, staff and volunteer student members of the campus community assist at each station, explaining the equipment in more detail, demonstrating advanced features, and answering any questions the students may have.

If time permits, following this self-directed exploration the group is brought back together as a whole and impressions are shared. And as time permits, a 3-D design module can be started, where students create an object through the 3DC.io app using a set of iPads owned by the College of Design. Designs are driven by students and can be inspired by movie or personal ideas and interests. The file can be saved and emailed to the classroom teacher, and the student can then take the file, perfect it, and take to a 3-D printer in their community to further realize the final product.

Since the launch in 2014, changes in dedicated personnel resources, technology, and funding streams have caused the FLEx program to evolve. One recent and notable program advance was a formal partnership between Iowa State University Extension and Outreach and the College of Design creating a shared faculty position with additional dedicated maintenance and operational funds for 3 years. This provides essential support for a program without a formal home base. This has been a critical step formalizing a pilot program and building future capacity. With this support are expectations that long term viability will rest on external funding. Still, the ability to reinvest in upgraded technologies and new strategies to deliver the program have moved the program forward. Logistical and extended program reach and support was realized in embedding the program in the Iowa State Extension K-12 4-H program.

Capacity building was also realized in a special related funding opportunity with the 4-H partnership. A request to build a professional learning kit as an introduction to the FLEx provided a new product to build and widen exposure opportunities to the program. Similar entry level technologies for VR, 3D printing and sample Little Bits were combined in a small luggage-sized mobile package. These were envisioned as tools for professional development, but were quickly recognized as additional scaled-down FLEx kits to engage youth for additional FLEx exposures in small group afterschool informal activities. This widens the program across the state at an introductory level but still provides traction and exposure for both students and additional logistical support.

With the pilot starting in 2014, technology has quickly evolved. A second generation form-factor with the next suite of tools has been envisioned and is being actively developed. Solutions to logistical challenges for scale and delivery are also being prototyped. One example technology is the VR headset Oculus Rift that started as the Developer Kit 1.0 in 2014 and is now in a full Commercial Version 1.0 (CV1 - two generations newer than the DK1). With this new capability, new applications and hardware configurations are required to deliver this as part of the FLEx experience.

Another aspect to the FLEx which requires discussion is curriculum. In discussions with both Iowa State Extension staff and Iowa Area Education Agency consultants for curricular development and programmatic developments, the concern was raised about short one-stop visits. This concern is valid from the perspective of a more recognized and formal educational setting and even 4-H where a structured day-camp is required to be 6hrs long. With many FLEx

visits interacting with youth for about an hour, this became a point for additional program development. What kind of curriculum would be appropriate? What area or domain should be focused on for programmatic work? What kinds of activities could students do with the FLEx in a longer workshop format? These type of questions seemed quite important to answer to be able to grow the FLEx to the next level where it would be embraced and recognized as an educational program.

In recognizing consilience (discussed in the introduction) as one factor shaping the contemporary world, consilience also impacts this immediate discussion about curriculum. The core of the FLEx is not domain specific. It doesn't preference a particular branch of science, math or area of study at all. The technology and ideas incorporated in the FLEx are described to students as pervasive technology that will impact all areas of work and living. And this is a core tenant of the FLEx for students to envision their future selves with access to advanced versions of these technologies and the impact to affect these technologies.

Stemming from a 4-H pilot of the FLEx in early 2017, it was proposed by a 4-H leader that staff were actually expected to take a general outline of the FLEx program and could then adapt it to any number of possible localized curriculum opportunities. For instance, one of the pilot day-camp programs incorporated wind technology and sustainability. Aspects of the FLEx program were woven into the activities and events throughout the day. In another day-camp, the FLEx was one of four stations that students rotated through during the day-camp which was focused on fine arts.

As the core of the FLEx is focused on emerging technologies and 21st Century skills (specifically the 4C's), the experience is focused more on life skills and personal educational development. This can be very adaptable to different curriculums. Without the curricular demand, the base core of the FLEx program can be more robust, stable and recognizable. Addressing curriculum can then be more focused as an extension to the FLEx from various scholastic curriculums or as a bridge from a more formal educational setting to a more informal FLEx program.

Pre-FLEx and Re-FLEx are early ideas envisioned as two such measures to address this opportunity. Local educators can work within the curriculum already on hand and identify opportunities that a FLEx visit may enhance. The local educator can coordinate with some Pre-

FLEx activities in the classroom with the curriculum in anticipation of a FLEx experience. One example would be early instruction on digital 3D modeling of the curricular focus. This preparation allows for one new activity, 3D modeling, to be integrated into the curriculum exposing students to understand their curricular topic in a new way while actually preparing materials that can be incorporated into a full FLEx visit.

One such Pre-FLEx example occurred at a school location in the spring of 2017 where students were studying cell structure. The students 3D digitally modeled basic concepts and ideas on a web application called Autodesk TinkerCAD (LINK) and some of these models were used for additional visualization on SEE station when the FLEx experience occurred.

As a Re-FLEx example in different summer 2016 camp, students used additional time around a FLEx event to design personal digital models on iPads using a design modeling program called 3DC.io (LINK). These digital models were downloaded and some were 3D printed on the MAKE station after the event, which can take significant time. Results were forwarded to the students by mail. These models were then used as a prototype for continued development in days following the FLEx event at school or online.

These two quick examples show that a FLEx event is extendable and not necessarily part of the event itself delivered to a school or camp. Local educators can extend their more formal time with students and curriculum to the transformative experience of FLEx which can offers both values of a unique impactful short visit with longer learning through the local educators around the event itself.

In addition, Chapter 3 discusses several aspects of perception and self-awareness, or congruence, which as a potential core topic itself seems appropriate for building a core FLEx curriculum. This would directly complement the personal development outcomes envisioned for the FLEx and may also advance students' capabilities with the emerging toolsets they find themselves surrounded by with a better skillset to reach their personal and educational potential.

Advancing ideas of Pre-FLEx, Re-FLEx, a core congruence curriculum, improving administration and logistics, and the continuing emerging technologies create enough of a

platform to build on with the initial experience of the FLEx pilot program. The FLEx appears effective which will be discussed further in the next section, Study and Findings.

Studies and Methodology

With the 175 FLEx sessions completed, there is a lot of anecdotal information and general feedback from instructors, students, teachers and parents. Overall, the feedback has been very positive. But there has also been a focus on implementation, program delivery, and program refinement after the first summer of development in 2014 which has also drawn attention away from developing the program for experiments to explicitly validate the program and ideas.

However, for this thesis, there were five sessions that included the FLEx, three of which were combined for one analysis, during the spring and summer of 2017 where Iowa State Extension 4-H collaboration and program development provided deidentified assessment information on the FLEx program. This provides a basis for an initial analysis on the FLEx.

Program assessment information is a typical part of a 4-H program protocol for internal program evaluation of all workshops, day camps or special programs. All children who take the program assessment sign assent or not upon registering for the camp in addition to a similar assent upon joining 4-H generally. The 4-H protocol is that only children with positive assent forms may participate in the program assessments.

The research question to guide the assessment questions were: (1) To what degree do youth participating in a Forward Learning Experience (FLEx) camp increase their knowledge of the Universal Constructs 4Cs (critical thinking, creativity, collaboration and complex communication? (2) To what degree do youth participating in a Forward Learning Experience (FLEx) camp increase their knowledge of the application of STEM and design thinking to their future?

The sessions to be analysed were all given an assessment at the end which included specific questions about the FLEx program. The sessions also covered three different sections of age groups in the K-12 educational space. The assessment varied in one session where the age group was K-5. Each session also differed in that the focus of the session was adjusted per a complementary program also running, from wind turbine technology to industrial design and

photography to fine arts, but the main content and components of the FLEx were consistent in all three sessions.

The first three sessions can be described as a day camp with a curricular focus on wind turbine technology and sustainability that used the FLEx as part of the central theme. The age range was 4th-8th grade and this six-hour day camp occurred three times over one month in the spring of 2017. A summary of the day's schedule end events is provided as part of the appendix, and each day there were twelve of more children in each camp. Over the first three sessions under this single curricular focus, there were 48 children involved. Each assessment included 9 questions which the child answered across a five point Likert scale. The following table is a summary of the responses with a discussion following all studies and tables. A sample assessment is included in in the appendix. Any additional information was not transmitted for analysis.

TABLE 1 4H FLEx WIND TURBINE CAMPS

GRADES 4-8, Iowa 4-H Youth, Spring 2017 (N = 48)	MODE	MEAN
Q1 - I like STEM *MORE* than before.	5	3.88
Q2 - I have a better understanding of how technology is important in my future.	5	4.05
Q3 - I have a better understanding of how technology is useful for solving everyday problems.	5	4.10
Q4 - I have a better understanding of a lot of ways technology can be used to solve society's problems.	5	4.17
Q5 - I hope to someday have a job related to STEM.	5	3.68
Q6 - I have a better understanding of how creative thinking is important for my future.	5	4.07
Q7 - I have a better understanding of how creative thinking is useful for solving everyday problems.	5	4.07
Q8 - I have a better understanding of a lot of ways creative thinking can be used to solve society's problems.	5	4.20
Q9 - I have a better understanding of the 4Cs of the Universal Constructs.	5	4.31

De-identified Program Evaluation Data from Iowa 4-H program which included the FLEx

LIKERT VALUES: 1 = Not at all, 2 = Very Little, 3 = Some, 4 = Quite a bit, 5 = A great deal

The next session for analysis occurred in the summer of 2017 was a combined five-hour day camp for FLEx and photography with a total of 22 students between 8th and 12th grade. The first half the group participated in FLEx during the first half of the day camp and then the groups rotated. Each assessment included nine questions which the child answered across a five point Likert scale and were the same questions as the FLEx Wind Turbine Camps. In addition, there was one multiple-choice question and a short series of open ended questions which will be presented following the next table. The following table is a summary of the responses with a discussion following all studies and tables. A sample assessment is included in in the appendix. Any additional information was not transmitted for analysis.

TABLE 2 4H FLEx PHOTOGRAPHY CAMP DATA

GRADES 6-12, ISU Summer 2017 (N = 22)	MODE	MEAN
Q1 - I like STEM *MORE* than before.	**4**	**3.91**
Q2 - I have a better understanding of how technology is important in my future.	**4, 5**	**4.09**
Q3 - I have a better understanding of how technology is useful for solving everyday problems.	**5**	**4.32**
Q4 - I have a better understanding of a lot of ways technology can be used to solve society's problems.	**5**	**4.09**
Q5 - I hope to someday have a job related to STEM.	**5**	**3.86**
Q6 - I have a better understanding of how creative thinking is important for my future.	**4, 5**	**4.23**
Q7 - I have a better understanding of how creative thinking is useful for solving everyday problems.	**4**	**4.05**
Q8 - I have a better understanding of a lot of ways creative thinking can be used to solve society's problems.	**5**	**4.18**
Q9 - I have a better understanding of the 4Cs of the Universal Constructs.	**5**	**3.91**

De-identified Program Evaluation Data from Iowa 4-H program which included the FLEx

LIKERT VALUES: 1 = Not at all, 2 = Very Little, 3 = Some, 4 = Quite a bit, 5 = A great deal

CIRCLE THE 4Cs	N=22
4 of 4	19
3 of 4	2
What did you learn today? key words/ideas...	**N=22**
Technology	7
3D printing	4.5
VR	3.5
Cool Stuff	2
Noise makers (Little BIts)	1
bamboo poison can be safe	1
eimucolse(?)... some part of the cyanotype?	1
mix chemicals and make art	1
considering going to College of Design	1
Favorite part of today? key words/ideas...	**N=22**
VR (roller coaster)	9.5
Blue photo thing (photography, pictures & art)	4.5
Little Bits	2
Everything	2

The third session for analysis occurred in the summer of 2017 was a combined four-hour day camp for FLEx and fine art activities with a total of 19 students between Kindergarten and 5th grade. Each assessment included three questions with a yes, maybe or no response to circle followed by a single multiple-choice question followed. The following table is a summary of the responses with a discussion following all studies and tables. A sample assessment is included in in the appendix. Any additional information was not transmitted for analysis.

TABLE 3 4H FLEx FINE ARTS CAMP DATA

GRADES K-5, County Art Camp, Summer 2017 (N = 19)	Yes	Maybe	No	TOTAL	MODE
Q1 - I like STEM more than before I came to camp.	**13**	5	1	**19**	**Y**
Q3 - I know more how technology helps solve problems.	**18**		1	**19**	**Y**
Q4 - I have ideas about how design thinking is important to my future.	**9**	8	2	**19**	**Y**

De-identified Program Evaluation Data from Iowa 4-H program which included the FLEx
VALUES MEAN...Yes, Maybe, No

CIRCLE THE 4Cs (identify)	N=19
4 of 4 correct	**18**
3 of 4 correct	**19**

Findings

The three sets of data for analysis from the 4-H sessions in the spring and summer of 2017 provide some valuable initial data points for evaluation and discussion of the FLEx project.

The first set, from Table One, shows a overall data return first with the mode, where if not every question posed returned a 5, the majority did respond a 5 or “A Great Deal.” This is significant in that the response showed a strong consensus of enthusiasm. The mode response shows that not only were the students engaged in a very positive manner, but they were tuned into the content and message in a very positive manner. This top response in the mode category also showed an overall enthusiasm that could be interpreted as a transformative experience. The mean of each question also showed this enthusiasm with additional clarity. The range of responses were from 3.68-4.31. The top third responses (4.31, 4.20 and 4.17) showed that the key most improvements according to the students responses were, in order of highest to lowest: (1) A better understanding of the 4Cs and Universal Constructs, (2) A better understanding of ways creative thinking can be used to solve society’s problems, and (3) A better understanding of ways technology can be used to solve society’s problems. This in general is strong response to the research questions. At the lower third the student responses (4.05, 3.88, and 3.68), in order from highest to lowest were: (7) I have a better understanding of how technology is important to my future, (8) I like STEM MORE than before, and (9) I hope to have a job related to STEM. These responses, while still high, show STEM could still be more inclusive and perhaps exciting in terms of what the students vision of how they might engage with STEM throughout their lifetime. And at the grade range of 4th to 8th grade, a career or job may not a top priority and a factor and that their future is fairly undefined in their minds leading to a less confident response. Overall, however, there is a positive trend in all the responses showing an

enthusiasm and confidence in the student responses indicating a potential for a transformative moment where the students are very positive about creative thinking, technology and understand the Universal Construct 4Cs.

The second set of data, shown on Table Two, supports the data from the first set, if just a bit lower in the values with responses that were still high overall. The mode returned five responses to the questions with the highest mode at 5, and two that were averaged at 4.5, and two at 4. The mean numbers ranged from 3.86-4.32. The top third responses (4.32, 4.23, and 4.18) showed some consistency with the first data set, but only close. The highest improvements from the student responses, in order from highest to lowest: (1) I have a better understanding of how technology is useful in solving everyday problems, (2) I have a better understanding of how creative thinking is important for my future, and (3) I have a better understanding of ways creative thinking can be used to solve society's problems. At the lower third the student responses (3.91, 3.91, 3.86), in order from highest to lowest were: (7) I like STEM more than before, (8) I have a better understanding of the 4Cs of the Universal Constructs, and (9) I hope to someday have a job related to STEM. These responses, also still high and also place STEM low and perhaps identifying a more inclusive career and area of interest. Interestingly there was a high response to creative thinking and technology, but a low response to Universal Constructs. This may be attributed to how creative thinking is presented as a more articulate way of problem solving and the 4Cs as a concept may seem simple to secondary students and hold less value. The similarities, though, in the high returns still amount to a positive experience and possibly a transformative experience at that.

The third set of data was a slightly different data set with the "Yes," "Maybe," and "No" responses, but still provide some insight into the thinking of the Kindergarten to 5th grade students. In the first statement, "I like STEM more than before I came to camp," over two-thirds of the respondents said "Yes," and almost another third said "Maybe." This shows a pretty convincing bump in the direction of considering that the student might like STEM more to even that they really do like STEM more. At this age they are also exposed to many new ideas and opportunities and, with the statement framed as it was, it shows a positive response and one that showed they connected to STEM in a positive manner. The second question was even more so in this connection and positive response. 18 of the 19 students responsed that, "Yes," they know more how technology helps solve problems. The present tense of the statement and the exposure the students experience of technologies most have not been exposed to shows

this is very effective for learning about technology. And in this case, with such a strong positive, this may be construed as a transformative experience as well. The third statement was not such a strong positive with nine “Yes” responses and eight “Maybe” responses and two “No” responses. Still trending positive with the “Yes” and “Maybe” responses together, but possibly the young students are not able to see their distant future as clearly.

In the second and third data sets, in addition to the primary questions and statements with the likert responses, there were a few more entries to analyze. In both cases, the students were presented with a series of seven “C” words with four being the actual 4C’s presented during the FLEx portion of the camp. In the second set of data, 86% were four for four correct and 95% were three for four correct. In the third set of data, 95% were four for four correct and 100% were three for four correct. This did show another measure confirming a positive increase in the students’ awareness and understanding of the Universal Construct 4C’s.

Lastly, in the second set of data, there were also two open questions. These questions were analyzed for key words and ideas. In the first question, “What did you learn today?” 32% wrote “technology” followed by 20% indicating “3D printing” and 16% indicating “VR” and 10% “Cool stuff.” The second questions was, “What was your favorite part of the day?” 43% indicated “VR” followed by 20% “Photography,” the other activity. Other responses to the second question also included “Little Bits” “Everything” “Technology” “3D Printer” and even “Eating lunch” which while only one or two responded in these ways, the “Everything” response was interesting as an open response from the students. Also from the open responses in general, there was a positive response and articulation of several of the aspects of the FLEx which was notable and probably a good reflection of different modes of learning and interest.

Overall, the data analyzed was only an assessment, which did not account for prior knowledge, which would be a stronger experiment. But the data showed a strong positive response for the experience in several ways. As an initial measure, the Forward Learning Experience elicits a compelling and positive reaction. The reaction shows potential as a transformative experience and appears to provide the students with a window to think about STEM, design thinking, emerging technologies and their (the issues and the students) significance in the world.

CHAPTER 6 SUMMARY AND CONCLUSIONS

This thesis is a trail of breadcrumbs. They exist. They connect. The connections together are important. But, as a colleague described, it can be like finding one's way through the house in the dark and with the furniture moved. It is important that the dots connect especially in this day of rapid technological change, social, political, cultural, and economic upheavals throughout the world. The dots do need to be connected a dot at a time scaffolding from one to the next, with deliberate confidence, care, and understanding.

This research and framework works with other tools that are emerging with today's digital native generation. Programming, which can appear abstract, can be demystified and made meaningful in a forward learning experience in addition to other formats and situations. Showing the underlying code, scripts and switches through 3D Printing, CNC machines can even be virtually experienced, and become clear and embodied in new virtual and telepresent scripting spaces in combination with other modalities of creative lessons through Processing, Python, Swift and other interactive programming. There is an immense amount of learning value providing the opportunity to see and experience the steps to create both real and virtual fabrications, to combine hands-on with tactile materials, and connecting the mind to visible, embodied representations.

A new language of programming and algorithmic thinking connected to physical and active, visual output is already starting to happen at an early age with Lego Mindstorms and Scratch by Mitch Resnick at the Lifelong Kindergarten Group at MIT. Additional software for coding is providing early access into these logic mindsets such as Codecademy, Tynker, Code.org, and Swift Playgrounds. New fabrication technology uses the same microprocessors that students are getting experience with through Processing and Arduino to control code, graphics, sensors, robots and milling machines. Creatively knowing this language and these machines can translate directly as a valuable professional skill.

Programs such as PLTW, FIRST Robotics and Engineering is Elementary are part of a first wave which are more structured as advanced technology integrated curriculums. Soon they will begin to be part of something more holistic which will incorporate flexible, adaptable and both structured and unstructured tool sets and advanced platforms meeting curricular standards. They will present pathways and scaffolds through new programming, modeling and visualization data-based tools for optimal localized, authentic, and individualized opportunities. Randy

Swearer, the former provost and dean of faculty at Philadelphia University and former dean at Parsons School of Design, even suggests we are shifting learning to a literal generative learning paradigm—collaboration with intelligent computer systems and active student co-creation as both “problem framer” and “curator” of the solution sets. This is an entirely different future for education.

Autodesk CTO Jeff Kowalski presented at AU in December 2015 and discussed four eras of computing: passive, generative, intuitive, and empathic. He suggested all of these are in the “augmented age” that we are currently entering into the generative era. This includes such tools as McNeel Rhino3D Grasshopper, Autodesk Dynamo, Dreamcatcher and Fractal, and Vectorworks Marionette. Marionette in particular takes the opportunity to expose and connect the code to its actions through the visual object-oriented interface into the visual scripting node and even to the programming behind the node itself allowing a dive into and connection between abstract code and concrete action. These are disruptive tools, not just reflecting conventions and methods from earlier days, that are affecting many disciplinary fields, professions, and industries.

Makerspaces are becoming Seeing Spaces (Victor, B., 2014) that recognize emerging ideas such as mediated spaces, mixed reality and the Internet of Things. These are all opportunities that today’s generation and the next generation onward, the digital natives, will work with and evolve to solve the problems of the day across disciplinary fields we recognize today and into new ones we do not. Emerging tools and opportunities will be challenging to anticipate, but a new skillset including programming and mixed realities will be part of the fundamentals. Schools are already allowing computer programming and languages to fulfill foreign language requirements. It is a mindset, a way of thinking for many already and a growing one for the emerging digital natives in school today. These new skills and mindsets can be understood, communicated and experienced from concept, to active virtual development and simulation, and to material reality.

Stepping beyond what Kowalski recognized as the generative era, a forward learning experience is a window into the intuitive and even empathic computing events he forecasts. A time not in the distant future when human-centered numeric control and mass customization are expected. Industry, education and learning will be redefined.

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APPENDIX 4H PROGRAM EVALUATIONS

Iowa 4-H Program Evaluation – FLEx: Wind Energy

Please circle the number that best fits your experience with this program.

After participating in this 4-H program:	Not at all	Very little	Some	Quite a bit	A great deal
I realize that I like science, technology, and engineering MORE than before.	1	2	3	4	5
I have a better understand of how technology will be important in my future.	1	2	3	4	5
I have a better understanding of how technology is useful for solving everyday problems.	1	2	3	4	5
I have a better understanding that there are a lot of ways technology can be used to solve society's problems.	1	2	3	4	5
I hope to someday have job related to science, technology, or engineering.	1	2	3	4	5
I have a better understand of how creative design thinking will be important in my future.	1	2	3	4	5
I have a better understanding of how creative design thinking is useful for solving everyday problems.	1	2	3	4	5
I have a better understanding that there are a lot of ways creative design thinking can be used to solve society's problems.	1	2	3	4	5
I have a better understanding of the 4 C's of Universal Constructs.	1	2	3	4	5

Circle the Universal Constructs 4 C's:

Creativity	Community	Critical Thinking	Connections
Collaboration	Complex Communication	Cooking	Computer Science

What did you learn today?

What was your favorite part of the day?

What didn't you like about the day?

IOWA STATE UNIVERSITY Extension and Outreach

4-H GROWS HERE

FOR OFFICE USE:

Program name:

Program date:

Adapted from Iowa 4-H Program Priorities Self-Assessment, Rev. Feb. 2016.

Iowa 4-H Program Evaluation – FLEx & Photography

Please circle the number that best fits your experience with this program.

After participating in this 4-H program:	Not at all	Very little	Some	Quite a bit	A great deal
I realize that I like science, technology, and engineering MORE than before.	1	2	3	4	5
I have a better understand of how technology will be important in my future.	1	2	3	4	5
I have a better understanding of how technology is useful for solving everyday problems.	1	2	3	4	5
I have a better understanding that there are a lot of ways technology can be used to solve society's problems.	1	2	3	4	5
I hope to someday have job related to science, technology, or engineering.	1	2	3	4	5
I have a better understand of how creative design thinking will be important in my future.	1	2	3	4	5
I have a better understanding of how creative design thinking is useful for solving everyday problems.	1	2	3	4	5
I have a better understanding that there are a lot of ways creative design thinking can be used to solve society's problems.	1	2	3	4	5
I have a better understanding of the 4 C's of Universal Constructs.	1	2	3	4	5

Circle the Universal Constructs 4 C's:

Creativity	Community	Critical Thinking	Connections
Collaboration	Complex Communication	Cooking	Computer Science

What did you learn today?

What was your favorite part of the day?

What didn't you like about the day?

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FOR OFFICE USE:

Program name:

Program date:

Adapted from Iowa 4-H Program Priorities Self-Assessment, Rev. Feb. 2016.

4-H: Fine Arts camp

Circle: Grade K 1 2 3 4 5

1.	**I like science, technology and engineering more than before I came to camp.**	**Yes**	**Maybe**	**No**
2.	**I did "hands-on" design using construction and decorating.**	**Yes**	**Maybe**	**No**
3.	**I know more about how technology helps solve problems**	**Yes**	**Maybe**	**No**
4.	**I have ideas about how design thinking is important to my future.**	**Yes**	**Maybe**	**No**
5.	**I did "hands-on" learning about acting.**	**Yes**	**Maybe**	**No**
6.	**I learned and did dancing for fun and exercise.**	**Yes**	**Maybe**	**No**
7.	**I worked well with others in the group.**	**Yes**	**Maybe**	**No**
8.	**The adult leaders were caring and kind.**	**Yes**	**Maybe**	**No**

Circle the 4 C words we talked about today.

Creativity Community Critical thinking Connections

Collaboration Complex communication Cooking Computer Science

What did you like best about the day?