ADDITIVE MANUFACTURING IN 3D PRODUCT DESIGN AND DEVELOPMENT PRACTICE: AN INTERDISCIPLINARY SHIFT

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Abstract

This paper reflects on aspects that impact on an interdisciplinary shift motivated by technology-transfer within a University of Technology (UoT). Discussion focuses on the integrated use of Additive Manufacturing (AM) as automated layer by layer 3D printing product design and development technology within a 3D Art and Design studio-practice environment. As emerging technology, AM's impact has redefined the procedural framework and required knowledge coherence for the development of 3D objects.

The paper takes a subjective approach to education and a culture of practice by identifying required knowledge coherence embedded in various interdisciplinary procedural actions that facilitate the use of AM technology in 3D product design and development studio-practice. The underpinning theoretical framework is located within a Constructivist paradigm marking a shift from discipline based learning to interdisciplinarity. This suggests that "procedural, student-centred" actions are defined by applying an inductive approach to knowledge generation, structured around emerging theoretical concepts. The paper explores synthesizing, constructing and producing as constructs that determine 3D studio-practice actions. Within each, a causal relationship exists between the actions that students take and the learning outcomes achieved.

In conclusion the paper proposes that students should be stimulated to engage in autonomous non-linear 'procedural, student-centred' actions, governed by technology driven improvisation, modification and evolution methods affiliated with 3D AM product design and development. Therefore, as reflexive practitioners students should demonstrate the facility to generate problem solving interdisciplinary incubation spaces rather than merely act on a discipline specific technology based problem solving strategy. Findings from this paper make a theoretical contribution to knowledge that expands on the interdisciplinary technology-transfer of AM technologies at a UoT.
Keywords: *Interdisciplinary, Additive Manufacturing, 3D Product Design and Development, Knowledge Coherence, University of Technology, Student-Centred.*

Introduction

Contemporary Art and Design practice demonstrates that cutting edge digital manufacturing technologies continue to permeate creative industries often resulting in distinctive hybrid outcomes. A perspective adopted by most Universities of Technology (UoT) within South Africa (SA), is to encourage interdisciplinary and transdisciplinary tertiary practice, "[…] to promote relevant research and development and to assist with the transfer of appropriate technologies […]" (SATN 2012). South African UoT's present an ideal context for the integration of emerging technologies, thereby presenting a platform that aligns educational practice with industry needs.

Currently, Art and Design programmes at most UoT's in SA focus largely on discipline specific methods and techniques embedded in traditional modes of practice. The integration of Additive Manufacturing (AM) technology into 3D Art and Design studio-practice at a UoT presents fertile ground to develop a sustainable framework for interdisciplinary technology based teaching and learning. The 3D printing technology termed Additive Manufacturing can be defined as the process of joining materials to make objects directly from 3D computer modelled data, using a layer upon layer automated manufacturing process (ASTM International Committee F2792, cited in Wohlers Associates 2010). Over a period of time this technology has been developed to print in a variety of materials, offering varied surface finishes and has the ability to print 3D form of varying complexity across several 3D industries: art, design, fashion, architecture, industrial, engineering, medical, film and animation.

At present few UoT's within South Africa have aligned their 3D Art and Design curriculums to include emerging AM technologies. Of the six UoT's in South Africa, the Vaal University of Technology, Vanderbijlpark and the Central University of Technology, Bloemfontein have aligned a portion of their 3D Art and Design curriculums to include computer aided manufacturing technologies. Both these Universities have well established AM technology stations that strategically engage with industry, therefore ideally positioned to partake in informal institutional technology-transfer and incubation initiatives within academic programs. Technology-transfer and product incubation initiatives yield maximum impact if Universities generate opportunities and resources for transdisciplinary interaction (Strom 2012, p. 8, 9).

Interdisciplinary practice

Advances in technology are propelled by globalization, which subsequently transforms conceptual and technical boundaries for most artistic product design and development activities. Globalization largely represents interdependence and interconnectedness, and is therefore stimulus for the constant need to review teaching and learning strategies within educational practice. As technology evolves it has become increasingly difficult to define discipline as a concept. The difficulty in definition is due to a discipline's body of knowledge continually adjusting to new ideas and applications (Hand, Mitrovic & Smyth 2010). Lack of clarity on what constitutes disciplinary knowledge holds significance when defining terms such as multidisciplinarity, interdisciplinarity, crossdisciplinarity, transdisciplinarity and postdisciplinarity. The literature offers varying opinions on what these terms specifically refer to. For the purpose of this paper discipline is defined by demarcating the boundaries of knowledge through acknowledgment of the field of specialisation according to the educational program. A shift to interdisciplinarity then challenges the disciplines' hold on knowledge and thereby more clearly defined in the context of a specific practice (Reybold & Halx 2012, p. 323, 324). Within this framework the context and practice of integrating AM technology within Art and Design programmes at UoT's is considered interdisciplinary practice.

Artists and designers continue to align their practice with technological developments, and in some instances are regarded as "hybrid-practitioners" (Rodgers & Smythe 2010). This indicates that contemporary artistic practice has surpassed traditional modes and embraces the interdisciplinary use of emerging technologies in various areas of product design and development. A fundamental challenge that confronts Art and Design educators is to constantly adapt curriculum content and teaching and learning strategies to align with the rapid advances in technology. The educational environment's neglect to adapt to developments in technology presents a challenge that could contribute to a disabling learning environment if not addressed (Asim, Oğuzhan & Ayşe 2011, p. 41). The inclusion of AM technology within traditional Art and Design programmes at UoT's in SA presents such a challenge. In order to avoid a disabling learning environment, 3D Art and Design studio-practice teaching and learning would benefit from an interdisciplinary "procedural, student-centred" approach that facilitates the integration of AM technology.

When introducing interdisciplinarity into a field, educators should be mindful that it should not replace the knowledge base of a particular discipline but should remain reliant on fundamental disciplinary knowledge for its further development (Weingart 2010; Frodeman 2010; Moore 2009). Therefore the objective is not to discard disciplinary constructs but to encourage sustainable interactions with other disciplines by building on a collective approach to knowledge generation (McCulloch 2012, p. 296). Within a UoT the transfer of practical and theoretical knowledge for the integration of emerging technologies across a range of subject areas requires interdisciplinary collaboration, embedded in dissimilar fields. This implies that interdisciplinarity be informed by content based curricula which provides the language and methods of knowing for generating renewed practice (Middendorf & Pace 2004, p. 6).

For interdisciplinary practitioners it is assumed that knowledge should ultimately unite dissimilar fields and therefore in the learning environment interaction takes on many forms, from the inclusion of discipline-specific vocabulary to an interdisciplinary way of knowing (Nowacek 2005). Such an approach is also referred to as "subject-symbiosis" where a teaching and learning strategy within education allows for interdisciplinary and multidisciplinary collaboration to take place (Seely-Brown 2008, p. 99). Within a curriculum structure knowledge coherence forms the criterion for curriculum quality and can be distinguished by how content is selected, sequenced and paced. The transmission of appropriate knowledge coherence through 'subject-symbiosis' and the adoption of a non-linear 'procedural, student-centred' learning approach presents a viable option for Art and Design programmes to integrate AM technology as strategic industry related 3D studio-practice.

Knowledge generation through coherence

According to Biggs and Tang (2007, p. 19) the student learning context refers to the idea that the student's perspective determines what is learned, not necessarily what the educator intends students to absorb. Therefore, teaching for many years has no longer been a matter of transmitting but engaging students in active learning from an individual's student understanding. Suited to this is the application of a constructivist approach to teaching and learning. This involves students acquiring new knowledge from the individual's active learning process, bringing about individual knowledge construction opportunities (Schuh 2003, p. 426). This approach activates the shift from surface learning to deep constructive learning. Conventional surface learning is a minimum effort task-orientated approach that employs low cognitive levels of activity (Biggs & Tang 2007, p. 22). The dimension of a learner's knowledge base is comprised of the following elements: strategic processing or executive control, motivation and affect, development and individual differences, and situation or context (King 2003, pp. 153-156). Therefore, to determine an effective outcome emphasis should be placed on how learning is guided and facilitated. A student-centred approach focuses on the educator's ability to promote active learner engagement; the promotion of learning through interactive decision making; and the educator being a reflective on going learner (ibid). However, to ensure the sustainable interdisciplinary technology-transfer of AM technology into the 3D Art and Design studio-practice environment requires more than the application of the widely used student-centred instruction (Weimer 2013, p. 45). In order to sustain connections between concepts and their applications the teaching and learning strategy should also be embedded with a system of knowledge coherence that is considered in relation to specific interdisciplinary activities and the intended outcomes (Young 2011). The technology-transfer of AM technology within 3D Art and Design studio-practice hinges on the educator guiding a 'procedural, student-centred' approach coupled with transmitting relevant knowledge coherence located in both disciplines.

Knowledge coherence outlines the form of internal curricula coherence, distinguishing between curricula which have conceptual coherence as epistemological core and those which have contextual coherence appropriate to a domain (Parry 2007). The more sequenced the curriculum the more valid the conceptual coherence and clearer the domain within which knowledge is generated. A less sequenced curriculum requires emphasis to be placed on the relationship between coherence and context, where external requirements play a significant role, therefore more suited to interdisciplinary teaching and learning (Muller 2009, p. 216). Conceptual knowledge coherence refers to the interdisciplinary and procedural knowledge base required to prepare students for occupational field/s. Contextual knowledge coherence reviews and questions specialised occupational practices in terms of interdisciplinary concepts from various curricula perspectives in order to determine commonalities. Professional knowledge coherence questions the significance of each curricula related part and how it enables the student to understand what it is to be a member of a particular profession (Young 2011, 2006a; Muller 2009).

Teaching and learning that includes conceptual, contextual and professional knowledge coherence has the potential to propel knowledge generation beyond surface learning towards a deep learning experience that stimulates high levels of cognitive activity (Biggs & Tang 2007, pp. 21, 24; Young 2011). Integrating AM into 3D Art and Design studio-practice requires a strategy that includes knowledge coherence to support the shift from a sequenced discipline specific understanding to a non-linear interdisciplinary mind set. In this instance knowledge coherence that aligns graduates with essential skills to increase their participation in the 3D product design and development industry. The sequencing and pacing of synthesizing, constructing and producing as non-linear procedural actions for the integration of AM technology within 3D studio-practice illuminates a renewed approach to 3D Art and Design practice for interdisciplinary curriculum integration. Interdisciplinary curricula essentially benefit from having both conceptual and contextual coherence when strategically aligned to a vocational domain (Muller 2009, p. 217; Young 2006a). This also implies that in order to keep abreast with global developments, the approach to knowledge generation within education should continually be reconsidered and critically reflected upon before it is endorsed (Raikou 2012, p. 417).

Additive Manufacturing in 3D Studio-practice

Outlining a sustainable 'procedural, student-centred' framework for the interdisciplinary integration of AM technology in a tertiary Art and Design 3D studio-practice setting has the potential to facilitate informal technology-transfer and knowledge generation that promotes innovation and growth beyond students' current UoT educational experience. As mentioned Universities are increasingly generating opportunities and resources for technology-transfer and industry incubation initiatives. The Technology Transfer and Innovation station located at the Vaal University of Technology's Science and Technology Park is an example of a facility that performs this function. The station stimulates economic activity by linking its rural/industrial environment to the urban environment of Johannesburg and Northern Gauteng (VUT 2013). Located within an educational setting this facility presents an ideal industry related context to facilitate the integration of AM technology into the 3D Art and Design studio-practice setting.

Synthesizing as concurrent approach

Synthesizing as construct in this paper refers to the co-creative collaborative process between the technology user and AM system as transformative 3D Art and Design practice. For product development and design it is essential to identify contextual commonalities from Art, Design and 3D printing domains when integrating AM technology in a 3D studio-practice setting. Establishing commonalities can be used as an educational instrument that blurs boundaries between subject specific content, thereby supporting a 'procedural, student-centred' framework that sustains interdisciplinary teaching and learning practice. The Department of Design and Technology at Loughborough University (now Loughborough Design School) in the United Kingdom, undertook a New Product Development research project that explored solving collaboration-related problems, by successfully integrating technology as an educational instrument. The objective of the project was to stimulate collaboration between industrial and engineering designers through the use of design representations. Technology was used to develop a shared understanding of a design representation system in order to improve interdisciplinary product design and development communication. Findings revealed that both design parties experienced high levels of effective interdisciplinary collaboration when developing a shared knowledge user design representation aid for multidisciplinary teamwork (Pei, Campbell & Evans 2010, pp. 159-166). Similarly, AM technology as design tool has the potential to advantageously equip graduates to perform as interdisciplinary entrepreneurs essential to the 3D world of work.

Problem solving for designers results in an open ended cyclical process of problem identification and problem solution (Cross 2006; Raikou 2012, p. 421). The effective cyclical approach to conceptual, contextual and professional knowledge generation and sequencing of synthesizing, constructing and producing as 'procedural, student-centred' actions has the potential to enrich 3D Art and Design students with learning experiences that encourage development through self-reflection and critique. This is reinforced by the understanding that an interdisciplinary educational environment refers to the actual crossover of boundary parameters, which facilitates the merging of established and new knowledge between dissimilar disciplines (Rikakis 2010, p. 4; Sullivan 2010, p. 117). Therefore, the fundamental determinant of interdisciplinary collaboration is being knowledgeable of the fact that research questions originate within practice and therefore are reliant on the ability to visualise relationships and structures within a conceptual framework (Nimkulrat 2007, p. 3; Mafe & Brown 2006, p. 5).

It is a common knowledge that the initial stages of developing any 3D product remain reliant on conceptualisation and visualisation skills, which form the most effective basis for developing projects with or without the use of emerging technologies. During the incubation phase of generating an idea, transformative learning entails a shift in consciousness activated by how we construct and reconstruct meaning from our lived experiences (Dirkx 2012, p. 400). Transformative learning as cognitive approach when applied in conjunction with an interdisciplinary informed problem identification, problem analysis and problem solving strategy supports the required conceptual knowledge coherence fundamental to a 'procedural, student-centred' action. Knowledge generation within the 3D Art and Design studio-practice environment therefore requires the conscious mapping of collaborative interdisciplinary practice as synthesized input, which determines an effective outcome.

Constructing as hybrid skill

Students within the 3D studio-practice environment naturally apply tactile modalities when modelling and constructing 3D form using malleable and rigid materials. Much discussion has been focused on how artists approach their work from positions of manual creators and digital selves when exchanging and integrating both procedures (Bowen 2010, p. 219, 220). Studies on modes of knowledge generation reveal that the construction of knowledge through the application of new content often stimulates procedural cartographic memory, also referred to as prior allocentric knowledge or tacit knowledge (Lafon, Vidal & Bertoz 2009, p. 541). Within the realm of aesthetics and perception, Richard Wollheim (1984) has also defined this concept as the artist and/or viewer being imbued with "cognitive stock". Touch and gesture as implied procedural knowledge actions prompted by prior knowledge function as an educational tool that has the potential to facilitate the shift from traditional hand skills to the digital realm. When engaged with interdisciplinary collaboration students should benefit from constructing new knowledge by drawing on prior allocentric memory embedded within their discipline specific fields.

Students need hands on experience and manipulative instructional resources guided and facilitated by; the educator's ability to promote active learner engagement; the promotion of learning through interactive decision making; and the educator being a reflective on going learner (King 2003, pp. 153-156). 3D Art and Design studio-practice instructional resources should place emphasis on the sensory modality which is regarded as a stronger modality and is known to achieve a more effective outcome over first development auditory and verbal modalities (Honigsfeld & Dunn 2009, pp. 221-223). 3D Product design and development is definitively dependent on contextual knowledge coherence which implies that students engaged in the process of developing a product require a reciprocal understanding of technique, material properties, manufacturing processes and final product assembly in relation to a specific domain. This reinforces the notion that the interdisciplinary integration of AM technology should not take place at the expense of abandoning 3D Art and Design discipline specific attributes, hence the inclusion of a teaching strategy to unlock allocentric prior knowledge. When using AM technology in 3D Art and Design practice both hand-skill and digital 3D studio actions share commonalities such as conceptualisation, object visualization, real and virtual world 3D constructing and modelling, and a range of AM technical know-how. This indicates that for the autonomous creator, a non-linear 3D studio-practice 'procedural, student-centred' framework requires renewed approaches to constructing as contextual knowledge coherence that accommodates the shift from traditional hand-skills to the digital realm.

Producing as automated process

In a culture that has become increasingly reliant on computers, automated product development raises issues on how digital technologies are affecting manual modes of art production. The seductive authority of digital production and the artists' yearning for the physicality of the material art object stimulates thinking about technology beyond mere function and raises debate about the technology in relation to authenticity. Walter Benjamin's (1969) seminal work "The Work of Art in the Age of Mechanical Reproduction" cautioned against technology denying the material "aura" of an artwork. Benjamin's (1969) theory suggests that the original artwork determines the prerequisite to the concept of authenticity. Current thought claims that mechanical reproduction releases the work of art from the "aura" of authenticity and therefore it ceases as prerequisite (Pinney 2002, pp. 4-6; Blythe 2001). Although AM systems are able to print in materials of quality, permanence, value and allow the freedom of almost unlimited complexity (Dean & Pei 2012), as automated ubiquitous process it still re-enters this contentious debate.

Shifting away from a linear discipline specific approach to teaching and learning allows curricula material to navigate students to understand what it means to be a member of an interdisciplinary product design and development profession. Hybrid aesthetic strategies examine the symbiotic relationship between art and technology, and thereby establish margins for future interdisciplinary technology-transfer. Presently these margins are bound by a state of tension between the position of new technology and the location of educational programmes, which continue to define how qualifications and their subject offerings are presented. According to Long Island University, New York curriculum instruction professors Choi and Piro (2009, p. 29-32), technology has become the new "alpha competency" and an indispensible skill for the future where cultural barriers dissolve in cyberspace. Students should therefore not be required to specialize in terms of their technical competency but rather form a theoretically informed mode of practice related to concept, context and profession.

This mind set is displayed in British artist Michael Eden's (2013) approach to practice, who explores the transition from traditional Ceramics hand-building skills to the digital realm by using 3D ceramic printing technology (See figures 1 & 2). Eden produces ceramic artefacts by way of dissecting and constructing form, exploring the relationship between the virtual and the actual, using primary geometric forms and mathematical models as vehicles. Being trained as a traditional Ceramicist has allowed Eden to develop a fine tuned sensibility for manipulating form. The automated ceramic AM process has allowed Eden to develop a sense of implied knowledge, where touch and movement are as important as sight in the subtle investigation of form. When using AM technology, Eden explores the ceramic vessel as a familiar distinctive object. However, the aesthetic nature of the automated AM process, transforms the representation of everyday functional object to be read as a paradox, an object containing an object or simply a void.

Figure 1. ***Maelstrom IV***, **2011, M. Eden.**

Figure 2. ***Bloom***, **2010, M. Eden.**

The world of work requires "hybrid practitioners" (Rodgers & Smythe 2010) and often when entering graduates find themselves insufficiently equipped to engage with the broad spectrum of industries using AM technologies. Theoretical and practical instances show that the application of a non-linear 'procedural, student-centred' product design and development strategy has the ability to inform an interdisciplinary knowledge base suited to a UoT 3D studio-practice setting. This allows students to emerge equipped with the potential to evolve from mere producers of aesthetic objects to understanding the product development cycle affiliated with the interdisciplinary practice that industry requires.

Conclusion

Art and Design curriculums at Universities of Technology (UoT) are usually procedurally conceptualized and therefore largely based on how to represent and analyse discipline specific contexts. Applying a non-linear deep learning approach to teaching and learning in 3D Art and Design studio-practice facilitates improvisation, modification and evolution methods for 3D product design and development. The effective non-linear sequencing of synthesizing, constructing and producing as 'procedural, student-centred' actions for the integration of AM technology allows for a renewed approach to 3D studio-practice. In addition to this, Young's (2011) suggestion to consider contextual, conceptual and professional knowledge in relation to one or more related disciplines enriches the knowledge coherence needed to define AM technology in 3D Art and Design studio-practice. Together these allow the educator to anticipate stimuli that facilitate active 'procedural, student-centred' collaboration. The integration of emerging AM technology is therefore viewed as new knowledge-construction for which the learner draws on traditional Art and Design practice as essential link to prior knowledge (Schuh 2003, p. 427). The integration of knowledge coherence coupled with access to prior knowledge within a 3D Art and Design studio-practice setting proposes to enable graduates to construct interdisciplinary knowledge that generates innovative solutions to industry's creative problems. This approach allows students to function as interdisciplinary reflexive practitioners that demonstrate the facility to generate problem solving incubation spaces, rather than merely acting on a discipline specific technology based problem solving actions.

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