Augmented Reality for Spatial Reasoning,

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As an educator and educational designer for a range for courses in computer aided design, a frequent challenge is implementing strategies to build and strengthen the capacity for spatial reasoning. Thinking spatially is a capacity that is essential for a student to exercise in product, interior, immersive, games and interaction design.

One of the courses I convene and teach is called *3D Modelling for Interaction*. It is a second year course in the Bachelor of Creative and Interactive Media at the Queensland College of Art/ Griffith University. The protocols for the course are to build skills in Three Dimensional Modelling, particularly in parametric modelling and polygonal or mesh based modelling. Conventionally one single course would not teach two markedly different software platforms. This course however is unique in that the theoretical foundations for it are introduced in a first year course where students are exposed to the ontological implications of the technologies and processes of design using computers. The affordances and constraints of design using computers are explored in other subjects within the degree, but in this course the ontological positions are directly negotiated whilst training in two markedly different applications for three dimensional modelling, namely Autodesk Fusion 360 and Autodesk 3DS Max.

Mathematically speaking the differences are that Fusion 360 is a solid modeller and 3DS Max uses boundary representation (Requicha 1980), (Requicha and Voelcker 1983). Both software platforms will permit objects and environments to be created through multi variant processes, but those processes can vary fundamentally in their mathematical origins. Conventionally a product design student would follow the conventions of the engineering paradigm and learn solid/ parametric modelling, whereas a games design student would learn boundary representation or mesh based modelling. This course is not bound by convention and strives to introduce students to the different strategies for three dimensional modelling as afforded by the different platforms, for the express purpose of challenging constraints imposed by insulation. Descriptive Geometry as an ontological constraint is also discarded in this course. That is not to say however, that it has no use. Descriptive geometry in the form of protocols and techniques for orthographic projection is a necessary and relevant form of communication to others (Huang et al. 2017) (González 2018). The parametric interface of solid modellers however were based upon the rules of descriptive geometry and in turn these rules constrained the ways in which the user interpreted and manipulated form.

Terry Winograd and Fernando Flores write of this concern using the standpoint of design. ‘In the act of design we bring forth the objects and regularities in the world of our concern. We are engaged in an activity of interpretation that creates both possibilities and blindness (Winograd and Flores 1987)’. Descriptive Geometry although powerful in building the capacity for spatial reasoning also suffers the constraints of reasoning within a Euclidean paradigm, that is describing the three dimensional interpolation of two dimensional forms through processes such as extrusions, revolutions, and Boolean operations. Solid modellers are wonderful tools for designing, but they can reveal the blindness of the descriptive process. Similarly polygon modelling software can reveal new possibilities at the expense of accurate and easily repeatable methods of description.

The goal of the course is to expose students to the technical and theoretical potential and pitfalls of tow somewhat contradictory computer aided design processes. This is achieved not by burying the students in theory that they don’t understand yet but by experiential learning through problem based projects. If the course began with reiterating the rules of descriptive geometry very little would be achieved as the constraints placed on the modelling process would limit the outcomes.

In terms of course objectives, *3D modelling for Interaction,* comprises two components, Six weeks of individual projects using solid modelling and six weeks of group projects using polygonal modelling. Students are provided with a set of assignment options for both projects and given the opportunity to deviate from or add to that list. It is imperative that individual students and groups work on projects that motivate them (Wei et al. 2015). As student motivation is a complex but necessarily personal set of issues, a suite of options to draw from has proved effective in previous courses. A secondary factor in allowing students to choose and help define their projects is that the time involved in one course is not enough to encompass the breadth of the software taught. It is imperative that students seek deeper learning of the components of the applications that they are learning and apply those components to solve problems that are meaningful for themselves. It is easy to become complacent as teacher in what is usually a pragmatic set of technical tasks in other institutions. Retaining a focus on problem based learning provides an opportunity for the otherwise mundane tasks of leaning software parameters to be enjoyable and challenging.

In Semester 1 of 2018, 66 students were enrolled in 3D modelling for interaction, divided amongst two campuses, serviced by two lecturers, Paul Bardini, specialising in solid modelling and myself, specialising in polygonal modelling. This offering was the second time in which a course had been split into two modules, so although the successes had been made in another course, this was the first time in which a computer aided design course had been so radically changed. From an external observer's position, this course may seem to exhibit novelty in many respects, but it is as a result of a long experience of teaching computer aided design that from our point of view the newly implemented elements of course design are logical decisions based upon student need. The decisions to implement somewhat contradictory modelling platforms in one course were in response to the diverse set of potentials we need to offer to our students in the newly formed bachelor of creative and interactive media. The graduate outcomes of the student contingent are diverse and not explicitly constrained to one discipline. One student, for example may graduate and require product design skills, and so skills in solid modelling will be of benefit. Whereas another student may build skills in projection mapping so polygonal modelling skills would be necessary. A course such as this is necessarily written to allow for a diverse set of experiences to be undertaken so that a great many opportunities be revealed to students. What is of importance, as well as course structure is the flexibility of delivery and the adaptability and guidance of the lecturers, a framework that could be construed as a Cognitive Apprenticeship (Brown et al.. 1989), Huang et al.. 2017), (Wu et al.. 2012).

The learning framework is firmly entrenched in Constructionist philosophies as espoused by Seymour Papert, (Papert 1993) as building on Jean Piaget's theories of Constructivism. In regard to this course a guided tutorial is delivered at the commencement of each class to negotiate key technical and conceptual issues pertaining to the task and the rest of the class is devoted to guidance and problem solving whilst students applied newly learnt procedure to their individual or group project. The crucial test of modelling abilities in a technical and conceptual sense is for students to realise their solutions to project problems in a tangible sense. Papert's ideas of experiential learning are crucial to how this course functions as the entire course is concerned with building the students skills and confidence not just in using software effectively but applying it to tangible problems.

The key concern of a course such as this is how students can experience a tangible solution to two diverse problem based assignments, within a short period of time. A previous solution to providing tangible solutions to problems incorporated the use of additive fabrication or 3D Printing. This occurred in a course entitled *advanced fabrication*. It was necessary in this present course to have faster solutions as 3D printing firstly can still take significant time to acquire the requisite skills, and secondly 3d printing is much more time consuming to adapt to modelled forms of larger scale and intricacy.

Augmented and Virtual solutions offer viable and seemingly tangible outcomes to a three dimensionally modelled product and particularly a modelled environment filled with furnishings and artefacts and mapped in materials. The decision to implement the use of augmented technologies in the classroom were based purely on purpose and not novelty, as it has been noted by other researchers that the use of AR by educators can be ad hoc (Billinghurst and Dünser 2012).

Having spent research time experimenting with various AR frameworks, it was a calculated decision to use *Sketchfab* as the platform to experience and test 3D modelled outcomes (Sketchfab 2018). A professional *Sketchfab* account was procured for the University and in the classroom students were guided in the creation of personal accounts so that as they worked towards resolved outcomes, they could effectively export and upload models to *Sketchfab* for experience and testing using a suite of the latest *iPad* using *ARKit*. *Sketchfab* is an ideal platform for experiencing modelled objects as it is multiplatform, using web, iOS and Android platforms effectively to view objects and scenes in AR and VR.

Simple singular objects such as the chair in *figure 1* were the first to be tested in AR as these types of objects could be tested for scale against a backdrop of real world proportions. Furniture items could first be tested for scale and secondly for application for material and texture. The impact on experiential learning is almost immediate not because the object in AR appears real but because it is believable, and it is believable because the barriers to disbelief are stripped away. The objects and environments modelled do not just reside within the computer in an abstract sense, they appear tangible as they can now be experienced at human scale against the backdrop of the real world. The experience of the object or environment in AR becomes, ontologically speaking, not just a visual representation, but a sensorial representation.

Figure 1. *Chair Modelled in 3DS Max by Cam Scott*

The object, in this case the chair can be experienced visually and haptically, it can be experienced and assessed in relation to the body that experiences it. It may seem like a novelty to a newcomer to these technologies but for students learning the procedures of three dimensional modelling and applying these procedures to seemingly tangible outcomes it provides a leap in spatial reasoning. In turn the AR frameworks simply become the new tools to model and test in increasingly swift design iterations. The successes of 3D modelling for interaction are not in the resolved and polished outcomes but in the flaws unveiled by testing quickly in AR.

There are multiple sets of interrelated procedures for modelling valid forms using solid and polygonal modellers, but little tolerance for error is acceptable for export for use in additive and subtractive manufacturing processes. The use of *Sketchfab* to import FBX files from *Autodesk Fusion and 3DS Max* helps reveal errors and inefficiencies within the design process, in terms of scale, proportion, modelling procedure and operands using Boolean union, intersection and subtraction to name but a few. *Figure 2* demonstrates a well modelled replica of a Roman stool which in *3DS Max* is quite convincing and shows careful attention to procedure and detail. Import to *Sketchfab* however reveals issues with the polygon mesh for the fabric that is then transferred to the UVW map for the material. If the teaching and learning experiences remain fixed to one software application the students would experience what is possible and what is blinding within that software application (Winograd and Flores 1987). Translating to other platforms and experiencing forms in AR helps to expose that blindness.

Figure 2. *Roman Stool Modelled in 3DS Max by Emily Zamattia*

Contextually modelling a roman era stool and situating it within a contemporary environment also enables a correlation between ergonomic principles applied to furniture from differing eras. Hannah Schraffenberger and Edwin van der Heide write of the relationships between the virtual and the real, inclusive of spatial relationships and content based relationships (Schraffenberger and van der Heide 2013), (Schraffenberger and van der Heide 2014). Emily Zamattia's Roman stool demonstrates the potential for coexistence of the virtual object in physical space, both in terms of spatial relationships and content based relationships, of the physiological correlation to form and of the tactile associations to materials and textures. Such an unravelling of potential is not easily possible in a conventional computer aided design course, but the immediacy of negotiating the relationships of virtual content in physical space permits this possibility.

A directly haptic association of virtual object and the human body is demonstrated in figure 3. This example was carefully crafted in *Autodesk Fusion* and exported as an FBX file to *Sketchfab.* The modelled set of objects demonstrate proportional structures relative to the human body designed and modelled quite accurately. Accessing the *Sketchfab* file using the *ipad* and *ARKit* help reveal and validate the relationship between the model and the body

***Figure 3**. Gauntlet modelled in Autodesk Fusion by Emily Zamattia*

As Schraffenberger and van der Heide accurately state. ‘The virtual not only relates to the real, the real also relates to the virtual. The spatial and /or content based relationships are *between* them (Schraffenberger and van der Heide 2014). Emiily Zamattia’s gauntlet evidences what the interactions between real and virtual can offer. It is in this liminal space that rapid advances can be made in the acquisition of new skills by their examination and verification using AR platforms.

The interactions of the object modelled in computer and the physical body is a very difficult and time consuming task particularly for novices just beginning to learn the software. The gauntlet is one of our best examples of rapid acquisition of technical skills in modelling, and conceptual skills in spatial reasoning that we have seen to date.

Figure 4. *Gauntlet by Emily Zamattia captured using ARKit.*

Some of the outcomes from the 3D Modelling for Interaction class, particularly environments modelled in *3DS Max* were best accessed in VR devices, for that purpose the entire models were exported prior to resolution, to *Sketchfab* and navigated via Browser with the *HTC Vive* headset. The environments were the more difficult assignment of the course as it requires careful adherence to modelling protocols and the appropriate sharing of files inclusive of models and materials within groups. The environments are a real test of modelling ability and export to VR is certainly not designed to penalise students for error but rather to reveal problems through navigation in VR so that they could be amended by returning to the modelling process.
The Villa as shown in *figure 5* is not perfect but is easily navigable in VR so that modifications can be made to the Max file and retested.
Navigation of the *Sketchfab* file is quite straightforward in VR using the *HTC Vive* and its teleport function. The immediacy of navigation affords almost instantaneous feedback as to the validity of the file, particularly its spatial connection to the viewer. Scale and proportion are the first to be tested as the students navigate their created space for the first time.

***Figure 5**. Roman Villa by Sarah Bidlake, Eva Chan, Jeffrey Handebo, Ning Yi Yeoh and Emily Zamattia*

Many students reported that they knew instantly what to fix as soon as they could view their environment in VR, and student groups were eager to return immediately to their files to modify their models and return to navigating and testing the environment in the next class. As an educator it was inspirational to witness such remarkable advances in spatial reasoning. I have taught polygon modelling for many years and know from experience how difficult it is for most students to grasp the essentials of computer aided design let alone achieve mastery.

Future iterations of this course will begin translation of objects and scenes into virtual spaces earlier. More *iPads* and portable VR headsets have been purchased for class use and will be available for continuous experience and testing. This being the first run of this particular course some of the outcomes can be introduced early to discuss the potential of the use of AR and VR. It is also expected that many more student users enrolled in this course from next year will have personal devices able to utilise *ARKit* or *ARCore* thus rendering the technologies further into the background of learning activities whilst permitting more time for experiential learning.

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