Design Education Forum of Southern Africa

Vulindlela – making new pathways

17th DEFSA conference – 21|22 September 2023

Bridging the gap between industry and the lecture hall: Small-scale manufacturing machines for experiential learning within the teaching environment

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Abstract

Students in Design Education are equipped to enter their respective creative industries. It is the intention that their skills and capabilities, once they graduate, are matched as closely as possible to the industries into which they will fit. During their time within the higher education faculty, they need to be exposed to relevant technologies and processes. By adapting manufacturing technologies for small-scale use in the classroom, students can gain hands-on experience and integrate these technologies into their learning processes.

Experiential learning methodologies will be unpacked alongside manufacturing technologies, which worked very effectively within the design educational environment. Students are able to gain practical experience in the manufacturing process, work collaboratively, and solve real-world design problems.

Over the past few years, several manufacturing technologies have been adapted for use in the industrial design lecture environment, including Rotational Moulding, Injection Moulding, Sand Casting, and Press Forming. Machines, tools, and processes have been experimented with and adapted to be operated on a small scale. Practical examples of these adaptations will be presented, including design outcomes that students have developed through their own project undertakings.

The results of students being able to replicate the manufacturing processes in the classroom environment have proven to be extremely successful, with project outcomes effectively illustrating large, real-world industry manufacturing concepts through practical demonstrations. The students' understanding of appropriate industry concepts is evident in their theory research reports, which are submitted alongside their project outcomes. Students document their own design process with reference to industry processes, illustrating their effective understanding of the core principles.

The value of students being able to visit industry partners during their studies is extremely high, however, simulating large-scale processes on a small scale within the lecturing environment allows students to experiment and learn hands-on in a free and safe working space prior to heading into industry. Furthermore, these small manufacturing machinery and tools are able to effectively manufacture small products and components at a suitable quality for incorporation into real product outcomes.

Keywords: Experiential learning, industrial design, small-scale manufacture.

Introduction

Students in Design Education are equipped to enter their respective creative industries with an understanding of the associated technologies and processes within these creative industries. It is required that their skills and capabilities once they graduate are matched as closely as possible to the industries into which they will fit. In this paper, the teaching approaches within a specific department of Industrial Design will be unpacked with examples illustrating innovative teaching approaches allowing students to engage with small machines linked to industrial manufacturing processes. The development of several of these small machines and teaching engagements are part of a doctoral project undertaken by the author, the ethics of which have been approved by the Faculty Higher Degrees Committee.

The core teaching method, which will be unpacked alongside examples, is that of experiential learning, which allows and encourages students to 'get their hands dirty' with the process of learning manufacturing within the classroom. During their time within the higher education faculty, students need to be exposed to relevant technologies and processes. While visits to large-scale industries are sometimes possible, it is not possible to do this often due to cost and logistical implications, and the department sees merit in attempting to bring these processes into the classroom.

Experiential learning in design

Experiential Learning Theory is an approach to teaching and learning that was introduced in 1984 by educational theorist David Kolb. The experiential learning cycle is a four-step learning process that is applied multiple times in every interaction and experience: Experience – Reflect – Think – Act (Experiential Learning Institute 2023). Brooks-Harris and Stock-Ward (1999) expand on what was first introduced in 1984 by David Kolb, that experiential learning is a cycle of learning that proposes four learning modes: concrete experience, reflective observation, abstract conceptualisation, and active experimentation. It is proposed that this experiential learning occurs most effectively when all four modes in this cycle of learning are engaged with effectively.

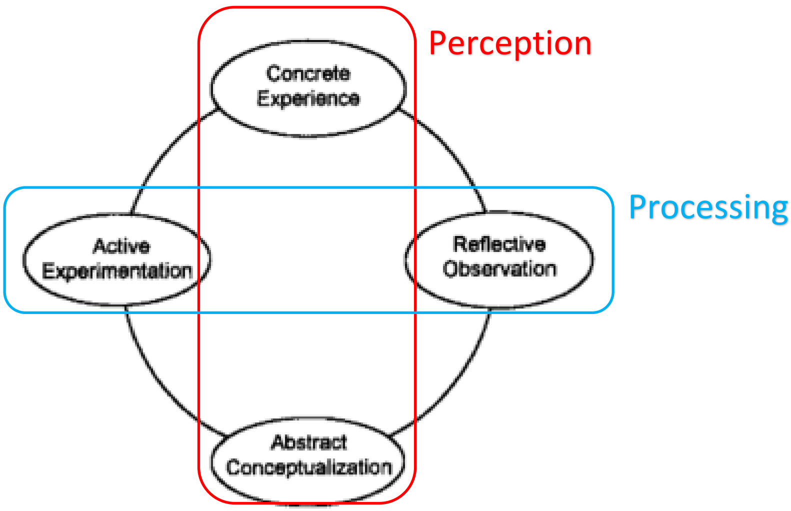

Figure 1: Kolb's Experiential Learning Cycle, Brooks-Harris, Stock-Ward (1999), adapted by Author

Of these four stages of a learning cycle, two primary steps stand out as core to the learning process. Concrete Experiencing of events, and Abstract Conceptualising (McCarthy, Brooks-Harris, Stock-Ward

1999). These were titled **perception**, linking to *concrete experience* and *abstract conceptualisation* and **processing**, linking to active experimentation and reflective observation. These have been highlighted in Figure 1. Through allowing students various methods of engaging with the learning material, it allows for different methods of learning to be grasped by students. Different students learn differently and touching on different ways of perception and processing can allow for a multitude of learning styles to be incorporated into lecturers.

It was highlighted in the foreword of *Diverse pedagogical approaches to experiential learning*, that good experiential learning with real-world issues is messy – and that is the intersection where good learning and good teaching reside (Lovett, K. 2022).

In the field of Industrial Design and neighbouring departments within the faculty, students, for the most part, are hands-on, and learning with practical engagement is a much better way to draw learners in, as opposed to digital presentations on-screen with a distance between the learner and the content.

With the delivery of theory modules within a largely practical course, how does one draw learners in, retain their interest, and have them actively engage with the lessons? Over the past few years, this question has been pertinent to a specific theory module relating to the Technologies associated with manufacturing processes in our department. In the past, almost all lecture content was delivered with the use of digital presentations and slides that have been altered year-to-year but did not seem to excite the students effectively. Generally, when one student falls asleep in a lecture, it is assumed that they have a lot on their plate and are tired [...], but when the third or fourth student dozes off, then it is enough evidence to point the finger at the lecturer and question the way in which they are delivering the lecture. Getting students involved with the content of the lecture, passing objects around, seeing in their hands what is being presented on-screen, and engaging with processes as depicted on-screen are all techniques that draw students in, and allow them to experience the content of the lecture in ways that are much more rewarding than lectures of the past. In Figure 2, a collection of students is receiving a technology lecture, but they have the opportunity to actively take part in the forming and manipulating of the materials, thus fulfilling the concrete experience and active experimentation aspects of Kolb's experiential learning cycle.

Figure 2: Students learning about moulds, press-forming experiments in class, image by Author 2023

Teaching manufacturing technologies

Lectures relating to manufacturing technologies require an understanding of large-scale processes that are being utilised in industrial sectors. Johannesburg houses one of the largest manufacturing sectors in Africa, and its manufacturing capabilities are extremely vast. The goal is, as much as possible, to expose students to these sectors with factory visits or projects collaborating with industry. With a defined theory lecture timeslot of only a few hours per week and a relatively large student body, it is difficult and often not possible to arrange site visits. Several industry contacts over the past year were approached and asked if students could visit, and many have indicated that smaller student groups are preferred. The ideal number is between six and eight people, to allow for a suitable group size to negotiate various factory operations whilst still being able to hear the discussions being relayed to students. Whilst splitting the 30+ student group down into four groups can allow for multiple trips, it does introduce excessive strain on the visiting factory, which is already sacrificing their capacity and time to assist with student tours. Splitting the groups into various factories also could be suitable, however, this again brings complexities for student management and safety.

Figure 3: Students visiting Rotational Moulding Factory 2019, department archive A. Marin

Practical-based projects that span several weeks allow for a more flexible timeframe and better student participation and collaboration. For instance, a keystone project undertaken annually with the second-year student body involves linking with the South African Association of Rotational Moulding. In this instance, the students are able to receive talks from industry partners as well as have walk-about tours in an identified manufacturing facility. This was possible with the Exam Project in 2019, with students visiting a Johannesburg-based Rotational Moulding factory (Figure 3). Again – the practical experience in the factory is invaluable for the Perception aspect of Kolb's theory, and also allows for reflective observation of the moulding process.

Adaptive experiential learning during the COVID-19 pandemic lockdown

During the COVID-19 pandemic lockdown, lecturers and students needed to become extremely agile in the manner in which practical and theory teaching takes place, as no links to industry were possible, and trips to manufacturers could not be made during that time. Even a trip to the hardware shop became impossible for a relatively long duration of time. Innovative problem solving is central to the design thinking process, and there are many different approaches that the department and its lecturers tried when engaging with the learners to promote experiential learning. One of the first in recent years that stands out as 'bringing manufacturing approaches into the teaching environment' is the sand-casting of sample objects with grocery-store-bought supplies, which was adapted in April

2021. This was due to the difficulty of not being able to take students to factory visits during the COVID-19 lockdown. Students needed to learn about Sand casting with molten metal, as illustrated in Figures 4 and 5, which is a very hazardous exercise to try and replicate without the correct infrastructure. The molten metal must be poured into a cavity within a compacted sand mould. The cavity within the sand gets filled, and once the metal cools, the cast item is removed from the sand.

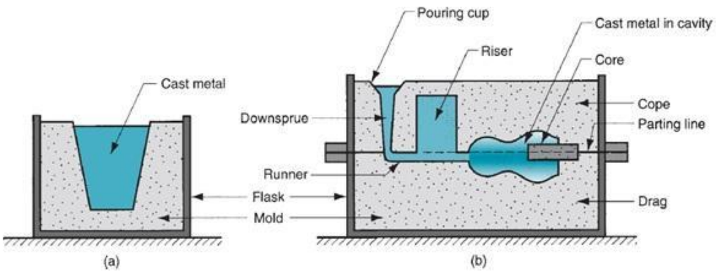

Figure 4: Left – casting molten metal with sand casting (Weld2Cast 2023)

Figure 5: Right – and casting process diagram (Engineering Product Design 2023)

Sharing online videos and photos of the process is able to effectively illustrate the process, but students inevitably miss out on the concrete practical experience aspect of experiential learning, which is such an important aspect of Kolb's experiential learning process. In order to overcome this disadvantage, sand casting was experimented on at home, with standard grocery store items purchased from the nearby store, as lockdown restrictions allowed. Replacing casting sand with cornstarch and molten metal with jelly snakes allowed for an interesting experiment that could be replicated easily and safely. This is shown in Figure 6 below, with the melting of the jelly babies being undertaken on a hotplate on low heat.

Figure 6: Process of casting molten gum sweets in corn starch, photos by author 2019

This casting process was repeated in-person in 2022 and 2023 with students on campus, and proved to be a messy-yet-effective method of teaching casting, going hand-in-hand with on-screen lecture content. The positive responses from students regarding this Active Experimenting within their lecturing environment were extremely encouraging, and the goal was then to adapt other manufacturing theories to a more hands-on teaching, allowing for more Experiential learning within the taught modules.

Experiential engagement: Additional machines and tools in the classroom

Over the past few years, several manufacturing technologies have been taken a step further and adapted for use in the industrial design lecture environment. These allow for in-class Rotational Moulding, Injection Moulding and Press Forming. The development of these two kinds of machines is linked to a doctoral study in developing small-scale manufacturing technologies, and the small size of these machines allows for them to operate effectively within the teaching and workshop environment. The following presents three different examples where the machines were used linked to teaching and learning, yielding effective experiential learning outcomes with learners.

Rotational casting prototypes

The rotational moulding machine illustrated in Figure 7 is the outcome of ongoing staff research with the development of small-scale manufacturing machines. It was utilised for in-class demonstrating of the rotational moulding process, which can be described as the production process of forming hollow parts with resin, which coats the inner surface of a rotating mould (Roto Mold USA 2023). This is the process that can make large plastic water containers and even hollow chocolate Easter eggs. During the COVID-19 pandemic lockdown, this was only taught through the use of online images and sourced demonstration videos, however, with this physical machine, students have been able to manufacture their own tools and cast their own products. This machine allowed for students to see how the machine settings and rotational speed and duration affect the hollow resin cast outcomes. The machine is also made available for students when they complete rotational moulding design projects, and has been effectively used for prototyping design outcomes on a small scale, simulating the larger industry process. In Figure 7, a student design process is illustrated from concept to final rotational cast prototype made in a 3D printed plastic mould, which can be used for the small-scale production process.

Figure 7: Rotational moulding as part of practical design process, department archive, Erasmus (2022)

In-class injection moulding

The injection-moulding machine is an open source from Precious Plastics, a Dutch open-source design collection of plastic processing machines, and was fabricated in the department workshop several years ago by an alumni. It was only at the start of 2023 that the machine was commissioned and started being used with experimental tooling. The first tool that was made was a small mould to injection mould a small game stacking chip. This machine was introduced to students as part of a plastics manufacturing lecture, where they first received a theory lecture regarding the types of plastics and associated methods of processing. Wheeling in a trolley into the classroom with a machine, bucket of plastic, and odds-and-ends in a box makes for an interesting lecturer entrance and immediately raises interest from the learners in the venue. The lecture trolley and engagements with the students are illustrated in Figure 8.

Figure 8: In-class injection moulding. Image by author 2023

What stands out with this engagement with the students was the variables to consider during the manufacturing process of injection moulding, being the cycle time between manufacturing objects, and the injection pressure of the machine, and the clamping force of the mould, all of which were able to be experienced hands-on in the classroom, which correlate to specific Large-Industry Injection Moulding considerations. Once the machine was introduced to the class, components were explained as the machine was heating up, and students were then invited to come and operate the machine. The small injection mould was bolted together with small fasteners, supplying the mould clamping force, followed by the hand-operated injection of the plastic and the holding of the pressure while the plastic cools within the mould. Lastly, the mould is removed and object removed from the mould. This is the same sequence in industry as moulds held together with clamping pressure, molten plastic is injected into the mould, and the holding and cooling time allow for the plastic to cool, after which the part is ejected (Essentra Components 2022).

Messy experiments with ceramic press forming

Figure 8: Press-forming clay with small countertop toggle press 'Little Squisher', image by Author 2023

The last example is the use of a small press-forming machine, which is again part of ongoing staff research into the development of small-scale machines. This is a hand-operated press that has been used for forming clay, pressing materials between mould halves, and also as a small printing press. For the in-class technology demonstration, it was used as part of a technology lesson about types of mechanical fasteners and later in the semester for illustrating how low-cost plaster moulds can be used to press ceramic clay into forms. Once the forms are dry, they can be fired in a kiln, yielding a final manufactured ceramic product. An interesting experiment with pressing clay against a leaf resulted in the 'printing' of the veins of the leaf into the surface of the clay. This opened up the inquisitive doors of experimentation for students to use the press for different tests with different materials, and in turn utilise it for the manufacture of ceramic tiles as part of a core design Practice Project during the semester. With an early prototype like this, the failed tests with moulds (at the expense of the lecturer) help inform the decision-making of the students. This is evident in the multiple broken Plaster-of-Paris moulds in the central image of moulds prepared by the lecturer for the experiential demonstration. Students also provide comments and suggestions to the lecturer for trying to make the press or moulds better for future tests.

Practical lessons learnt, linking to manufacture process variables

Many of the considerations that affected the outcomes of the abovementioned in-class manufacture examples link directly to manufacturing considerations within associated manufacturing processes. For example, manufacturing variables that affect the quality of a component could be process pressures, temperatures, times, and speeds (Figure 9, Kuts 2005).

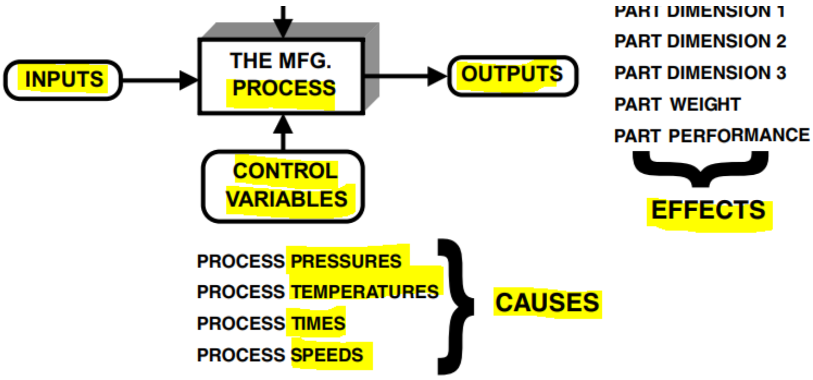

Figure 9: Process variables leading to output variables (Kuts 2005)

Variations in any of these can effect the output qualities. Students know this through their individual experiences.

What is exciting, though, is the natural inclination for students to question what the outcome might be if different variables are used. "*What will happen if more pressure is applied?*"; "*Can you use two colours at the same time?*"; "*Do you think this could work with natural bio-plastic?*"

The response I provide to the students is: *'I'm not sure, try it and see what happens!'* and leave the machines with them, encouraging them to uncover and document their new experiences.

Some points from student feedback or reflections regarding these various examples that stand out are as follows:

- I would like to attempt to build one of the small machines.
- It opens up ideas to create tools and machines to help in the manufacturing process.
- It makes the class more interesting and fun, which leads to more people paying attention.
- It gives a more in depth and practical learning experience as opposed to learing with powerpoints, this is advantageous as industrial design is also a practical course.

Conclusion

The presented examples, and their alignment to both Experiential Learning Theory, and Manufacturing Processes, illustrate interesting and novel approaches to teaching manufacturing theories, practically, within the lecturing environment. What started as experimenting with cornstarch during the COVID-19 pandemic lockdown sparked interest in pushing boundaries with trying to engage more effectively with students in their individual learning journeys. Not only is it more engaging and interesting for the learners, it is also more exciting for the lecturer, constantly stimulating more ideas with how lectures can be delivered. The ability to teach students practically with the small-scale machines in the lecture rooms is providing extremely positive results. Increasing the collection of teaching machines to replicate each large manufacturing process can allow for the teaching environment to be considered a factory of mini machines for experimental product tooling and manufacture. The depth and manner in which students engage with theoretical teaching content is much more effective with the inclusion of experiential learning in the delivery approach. Students show evidence of grasping the theories, and process the information much more effectively than just digital in-class presentations.

References

Brooks-Harris, JE, Stock-Ward, SR 1999, *Workshops: designing and facilitating experiential learning*, SAGE Publications, Thousand Oaks.

Engineering Product Design 2023, *How does the sand casting process work?,* viewed 12 June 2023 <https://engineeringproductdesign.com/knowledge-base/sand-casting/>.

Essentra Components 2022, *What is plastic injection molding and how does it work?*, viewed 1 March 2023 <https://www.essentracomponents.com/en-us/news/manufacturing/injection-molding/what-is-plastic-injection-molding-and-how-does-it-work>.

Experiential Learning Institute 2023, *What is experiential learning,* viewed 20 June 2023, <https://experientiallearninginstitute.org/resources/what-is-experiential-learning/>.

Jenkins, TS 2020, *Reshaping graduate education through innovation and experiential learning*, IGI Global.

Kuts, M 2005, *Mechanical engineers' handbook: manufacturing and management* (vol. III), London, Wiley.

Lovett, K 2022, *Diverse pedagogical approaches to experiential learning*, vol. II: *multidisciplinary case studies, reflections, and strategies*, Berlin, Springer International Publishing.

RotomoldUSA 2023, *What is rotational moulding?,* viewed 24 May 2023 <https://rotomoldusa.com/rotomold/>.

Weld2cast 2023, *Sand casting: why choose sand casting?,* viewed 12 June 2023 <https://www.weld2cast.com/sand-casting/>.