INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
7 & 8 SEPTEMBER 2017, OSLO AND AKERSHUS UNIVERSITY COLLEGE OF APPLIED SCIENCES, NORWAY

GIZMO – ARCADIA, THEATRE, CREATURES AND ORCHESTRA

Andrew BRAND and Peter CHILDS
Dyson School of Design Engineering, Imperial College London, United Kingdom

ABSTRACT
Gadgets enthral and delight. We are surrounded by the outcome of centuries of invention and associated refinements of machines enabling our lives. Many of these rely in their formation on prior technology and knowledge. It is this prior knowledge that provides a stepping point and foundation for design and realisation of a gadget.

This paper reports the long-standing 'gizmo' module that has been run on multiple occasions and in various formats each year at Imperial College London and the Royal College of Art. The module provides a foundation in mechatronics, coding and machine design to serve as building blocks for students' self-generated ideas and prototypes for their gizmos. Exposure to a wide range of sample parts, coding sessions, practical build and integration of circuits and actuators has been found, in combination with a culture of adventure and freedom from a prescriptive brief, to result in significant and accelerated learning for students of diverse backgrounds.

The module's characteristics include a culture of adventure and ambitious builds, intensive activity, serendipity and celebration of failure and success.

Keywords: Machine design, mechatronics, coding, adventure.

1 INTRODUCTION

Mechanisms abound in engineering and design. A designer, almost regardless of discipline whether fashion, jewellery, vehicle and product or furniture, is likely to use mechanisms exploiting their technical function to fulfil a useful purpose. Similarly, from aerospace and construction to electrical and petroleum industries, engineers will likely use mechanisms in their work. Mechanisms comprise parts that work together to fulfil a function. Mechanisms were originally physical in nature, although the electrification of many systems resulted in a drive towards electro-mechanical or electrical sensors and actuators. Hybrids are possible as are intelligent or quasi-intelligent mechanisms enabled by sensors and control systems or exploiting control algorithms in their form. A contemporary example is toe of some pedipulators inspired by a mountain goat's anatomy [1].

The wide use of mechanisms across engineering and design provides a motivation for their consideration in education. Their reliance on mechanical and electrical principles, materials and control proffers a platform for learning important subjects. This is the world of gizmo, introducing students from diverse backgrounds to the fundamentals and practicalities of mechanisms. This paper provides a description of a module designed and developed to introduce students from diverse backgrounds to a wide range of mechanisms, their principles and potential applications. The module is taken by both design engineering undergraduates and masters students and has been undertaken by over 15 cohorts. Section 2 provides a description of the design of the module, Section 3 some of the outcomes and Sections 4 and 5 address discussion of the results and outcomes as well as conclusions.

2 THE GIZMO MODULE

Mechanisms have traditionally been considered in engineering degrees in modules such as mechanics, mechanical design and control. A typical approach has been to consider their function accompanied by detailed analysis of their dynamics and failure modes. This provides a thorough foundation to the topic but does require prerequisite skills in, for example, engineering mathematics, materials and mechanics. An alternative is to take a problem based learning or project based learning approach and inspire interest in the mechanism concerned and associated subjects as a result of the need to deliver a solution or project. These approaches have been well documented by the SEED (Sharing Experience in Engineering Design) organisation as well as more recent EPDE papers (see for example [2], [3] and [4]).

The Gizmo module was defined originally in 2008 to provide learning for masters' students on the Innovation Design Engineering (IDE) masters programme in the mechanisms and associated technology. The Innovation Design Engineering programme is a double masters run by the Royal College of Art and Imperial College London. The programme has a long heritage having run since 1980 and has a focus on producing entrepreneurs and change-makers [5]. A particular feature of the degree is design through making and prototyping with students being able to select between an experimental design and a disruptive market innovation pathway. In order to help students build their skills in prototyping, the Gizmo module was defined to include exposure to a wide range of mechanical machine elements, in combination with an introduction to a micro-controller, sensors and actuators so that students may use these as building blocks within their emerging concepts and project work.

In early versions of the module, a simple brief was used as a provocation for students to engage in learning of the fundamentals and practical implements of machine elements and electronic effectors. The brief required students to design, build and demonstrate a mechanism that fulfilled a useful function and used at least six different machine elements. Alternatively students could elect to produce a kinetic art form that used at least six different machine elements. A three to four week intensive period was defined for this module during which time students undertook few if any other major learning activities enabling concentration of effort. The brief was defined in order to provide a motivating factor for learning and this tended to result in demand early in the module for presentations and provision of learning materials on basic machine elements and electronic effectors. Such materials were duly rolled out with the majority having been anticipated by the module team. As students were open to define their own solutions there were however inevitable surprises in the requests for diverse support. The module was run in this form for several cycles gradually establishing the Gizmo module as a firm favourite and in demand, with repetition of the module for a few cohorts of students each year. By the time of writing the module is now run for students across several different degree programmes ranging from the MEng in Design Engineering (DE), IDE, the double masters in Global Design Engineering [6], visiting students from Keio, the Pratt Institute, Tsinghua and the National Technical University of Singapore.

The diverse backgrounds of the students have resulted in development of the module brief and adoption of a series of interventions in order to ensure accessibility to the learning materials. In addition the expansion of numbers of people undertaking the activity also provided the opportunity to explore more adventurous collective undertakings where the individual or group projects could be combined to produce a collective outcome. In this regard, recent Gizmo modules have adopted a unifying theme that changes each time the module is run; examples include "Arcadia" games à la coin-operated working models, biological inspired minimal "Creatures" (video at bit.ly/GizmoCreatures), and an electro-mechanical sound making "Orchestra". A thematic approach allows learning materials and the project structure to be reused, whilst providing direction for radically different outputs each time.

The current Gizmo is a newly created module in the Dyson School of Design Engineering that is compulsory for second year undergraduate students from the Design Engineering MEng programme and first year postgraduate students from the Innovation Design Engineering MSc and Global Innovation Design MSc programmes. All three student cohorts attend Gizmo classes ("lectures") at the same time, twice weekly, but separate lab sessions, tutorials and formal reviews. The Gizmo module combines the approaches of physical computing and mechatronics. It is a foundational course that assumes participating students have elementary or no prior knowledge of these subjects, but requires significant out-of-class time and effort. Most of the real work happens outside of class, with students building in workshops and programming, and interacting with their peers and the module's tutors. The general and broad intention of the Gizmo module is to develop students' ability to think inductively, critically and solve problems with regard to the design of electro-mechanical systems. The module provides the first integrative step in a physical computing pathway that runs throughout the four years of the undergraduate Design Engineering MEng course by building on and bringing together learning from four modules that are undertaken in the first year of the programme. Accordingly, content of lab sessions and expectations (assessments) differ slightly for the MEng cohort to the MSc cohort, many of whom have not previously studied engineering in higher education. Successful completion of Gizmo does not transform beginners into expert mechatronic engineers, but the ambition is that students retain essential concepts, acquire language and jargon specific to the subject area and develop their own heuristic methods that can be recalled later in their studies and professional practice.

In the Gizmo module, students learn to design and build alpha prototype devices that integrate machine elements such as bearings, gears, cams and mechanisms with simple feedback control systems, in which a variety of sensors and actuators are connected to a microcontroller or single board computer. Gizmo is not a distinct mechanics or electronics or programming course or, indeed, a design course. Gizmo provides a broad overview of tools and techniques used in Physical Computing and Mechatronics, with particular emphasis on machine design sourcing many materials from [7]. Students learn about three broad areas in this module as follows.

- Students are introduced to the modelling, integration and best practices for use of machine elements such as bearings, gears, cams and mechanisms.
- Students are introduced to simple feedback control systems, consisting of actuators such as motors, sensors such as switches, basic electric circuits and microcontrollers or single board computers for comparing signals and driving actuators accordingly.
- Students are introduced to the rudimentary programming of microcontrollers or single board computers to affect an outcome, and how to interface the digital and physical world.

Gizmo takes an active learning approach, which means that students spend a lot of time sketch prototyping, building mechanisms, making and integrating machine elements and actuators, building basic circuits, soldering, and writing programs to affect a specified outcome in a learning environment where theory is linked to practice for specific applications and then generalised. The benefits of an active approach, compared with a more conventional, lecture-based ("transmission") approach, are widely accepted [8], [9]. The learning environment, which is partly made possible by a team of multi-disciplinary, adaptable and knowledgeable tutors is an attempt to develop a constructively aligned module curriculum, in which students engage as agents in their own learning; an approach developed on and advocated by [10] with various studies to corroborate these premises in studies related to learning and teaching in engineering [11], [12].

Students fully engaged with the module, should be able to distinguish between a wide range of machine elements and electronic components and select appropriate hardware for their application; construct working sketch models of machines confidently and quickly; develop and refine complex machines through synthesis, analysis and prototyping; integrate hardware (e.g. machine elements, structures, electrical components, micro-controllers, sensors) and high-level programing languages such as Python. Students are encouraged to show invention and creativity throughout the module, in relation to their approach and the embodiment of their machine.

3 OUTCOMES AND DATA

Students' learning is assessed through demonstration and inspection of their Gizmo machines and by viva presentation to a panel of experts. Students also submit a short report that describes their inspiration, materials and methods (including research, ideation, analysis, simulation, iterative development and manufacturing), and a statement of roles, main contributions and reflection by each member of the group. Crucially, students share their code through a web-based repository and produce videos of their machines as an archive for the projects. Example descriptions, produced by the IDE and DE student teams, of a few Gizmo projects are given in Tables 1 and 2. The tables also include us blinks to videos and a corresponding summary of the principal machine and control elements exploited in the project. Figure 1 shows images of two Gizmo machines as a snapshot representation.

Table 1. IDE Gizmo project descriptions

Gizmo description	Weblink to video	Principal element(s)
"Medusa Meccanica" is an electro-mechanical Gizmo that emulates the motion and aesthetic of a jellyfish.	https://bit.ly/MedusaMeccanica	Crank slider, recirculating ball mechanism, geared DC motor
"Inkey" is an analogue interactive musical loop machine, in which players trigger various instruments by applying colour dots and dashes to a conveyor belt surface.	https://bit.ly/InkeyGizmo	Conveyor belt, gripper (linkage), solenoid and servo motor, photo-resistor sensor

"Flock" is a system of autonomous robotic Peruvian water whistles with emergent behaviour. From ancient and new technologies, a non-composed dialogue emerges from their interaction	https://bit.ly/FlockGizmo	Cable & pulley, rolling element bearing, stepper motor, microphone, emergent algorithm
"Gizduo" A bellows-powered, Arduino-driven, harmonica-playing and finger-drumming machine.	https://bit.ly/GizduoGizmo	Crank, linear bearing, timing belt & pulley, radial bearing, pneumatics, piezoelectric sensor, event-driven programming
"Ido" is an interactive mechanical installation that uses capacitive sensing to trigger sounds and motion	https://bit.ly/IdoGizmo	Push-pull cable & pulley, linkage, servo motor, capacitive sensor

Table 2. DE MEng Gizmo project descriptions

Gizmo description	Weblink to video	Principal element(s)
"BMIC" is a drum sequencer that comprises three un-pitched percussion instruments; bass drum, snare drum and cymbal.	https://bit.ly/BMICGizmo	Linkage, solenoid
"Back Street Brush" is inspired by the theatre production 'STOMP', and comprises drum, brush and shakers.	http://bit.ly/BackStreetBrushGizmo	Scotch yoke, linkage, shaft coupling, DC brushed and stepper motor, solenoid, microswitch, photo-resistor sensor
"Chordocentric" generates sound from an array of vibrating strings that are moved in and out of the path of a rotating pluck to generate a melodic sound.	https://bit.ly/ChordocentricGizmo	Timing belt & pulley, shaft connection, radial bearing, linkage, servo, piezoelectric sensor
"Chymbal" provides melodic sound from a set of chimes, while a brushed cymbal generates a continuous background noise.	https://bit.ly/ChymbalGizmo	Timing belt & pulley, slew bearing, linear bearing, linkage, stepper motor, solenoid

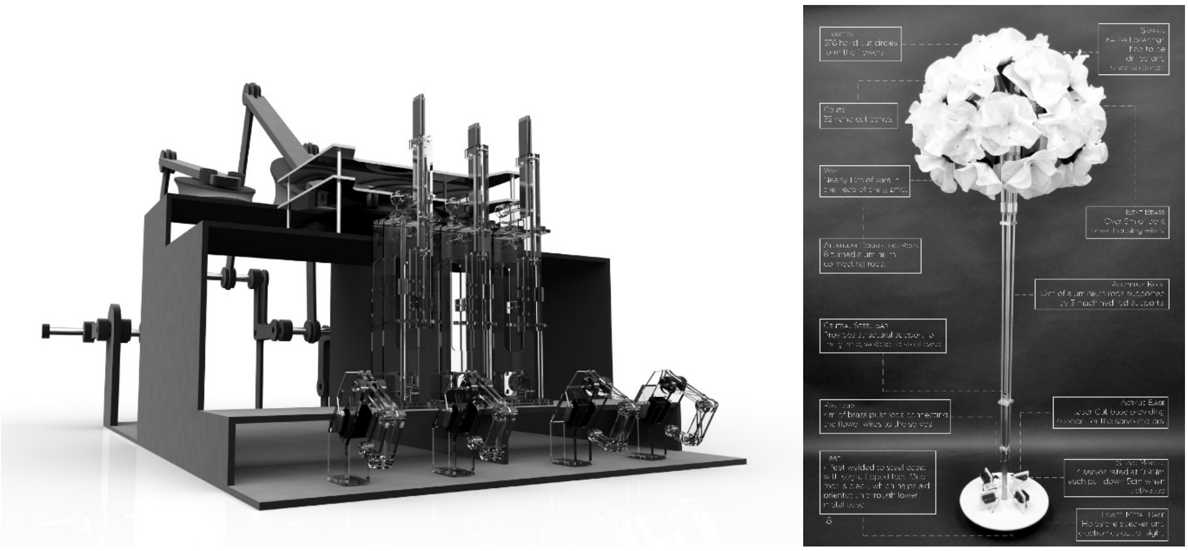

Figure 1. Examples of final outputs from the cohort of IDE 2016

4 DISCUSSION

The project based nature of the module results in substantial engagement by the student teams with high levels of tutorial interactions and workshop activity. Instances of group issues, such as fallouts, non-attendance or contribution, have been rare indicating that the combination of project activity, nature of the project, on-demand subject consideration and resourcing for projects has produced a culture that inspires activity.

For the projects listed in Tables 1 and 2 some indications of clear subject learning are identifiable, with the following comments based on a combination of tutor feedback and student reflection:

- Medusa Meccanica - New skills and understanding acquired in vacuum forming, sand blasting, silicone casting, welding.
- Inkey - New skills and understanding acquired in designing and building flexible drive systems, with applied external loads, daisy chaining Serial Peripheral Interface devices.
- Flock - New skills and understanding acquired in designing and building cable and pulleys, precision controlled stepper motor systems, and emergent algorithms.
- Gizduo - New skills and understanding acquired in designing and building pneumatic systems, sliding mechanisms, stepper and servo motor control using event driven programming.
- Ido - New skills and understanding acquired in designing and building positional cable systems, metal turning and fabrication, programming for capacitive sensors.
- BMIC - New skills and understanding acquired in designing and building electromechanical systems through an iterative process.
- Back Street Brush - New skills and understanding acquired in designing and building reciprocating and rotating machines, motor control, synchronising actuators.
- Chordocentric - New skills and understanding acquired in designing and building a flexible drive, multiple servo controls, linking Arduino and Raspberry Pi.
- Chymbal - New skills and understanding acquired in designing and building linear, position controlled belt system.

5 CONCLUSIONS

Although project based and active learning are well-known for producing embedded learning outcomes, challenges remain in the practical implementation of such schemes, ranging from the resources required, culture and teaching skill base. The Gizmo module has embraced active learning with student generated project ideas that need to be designed, built and demonstrated. The challenges associated with project based and active learning are compounded by a student demographic from varying backgrounds and levels. A series of interventions have been adopted to assist in aiding student learning attainment and providing a positive student experience including a culture of student generated designs, on-demand curriculum content and student directed tutorials, database of technology hints and guides and a collective project output celebrated with an exhibition of students' final outputs.

REFERENCES

[1] Abad G., Sara, A; Sornkarn, N; Nanayakkara, T. *The Role of Morphological Computation of the Goat Hoof in Slip Reduction*. IEEE International Conference on Intelligent Robots and Systems. 2016.

[2] SEED. Curriculum for design. *Engineering undergraduate courses*. Proceedings of Working Party, SEED, Sharing Experience in Engineering Design, 1985.

[3] Childs, P.R.N., McGlashan, N.R., Aurisicchio, M., Gosling, G. *Linking design, analysis, manufacture and test in the engineering student experience*. Paper EPDE2010/216, In Boks, C., McMahon, C., Ion, W., and Parkison, B. (Editors), When Design Education and Design Research Meet. 12th International conference on engineering and product design education. Norwegian University of Science and Technology, Trondheim, Norway, pp. 210-215, 2010.

[4] Masen, M., Brand, A., Yan, Y., Varley, J., Childs, P.R.N. *Demanding it all from the novice Mechanical Engineer through Design and Manufacture*. EPDE14, 2014.

[5] Childs, P.R.N., and Pennington, M. *Industrial, and innovation design engineering*. In Chakrabarti, A., and Lindemann, U. (Editors) Impact of Design Research on Industrial Practice, pp. 133-149, Springer, 2016.

[6] Stevens, J., Fujikawa, M., Mueller, K., Childs, P.R.N., Pennington, M., Lundberg, S. *Design without borders: a multi-everything masters*. LearnX2015, 2015.
[7] Childs, P.R.N. *Mechanical design engineering handbook*. Elsevier Butterworth Heinemann, 2013.
[8] Freeman, S., S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth. *Active learning increases student performance in science, engineering, and mathematics*. Proc. Natl. Acad, 2014.
[9] Wieman, C., Gilbert, S. *Taking a Scientific Approach to Science Education, Part II—Changing Teaching*. Microbe—Volume 10, Number 5, 2015.
[10] Biggs, J and Tang, C, *Teaching for Quality Learning at University. What the Student Does*. 4th edition. Maidenhead: Open University Press, 2011.
[11] Hesketh, R., Farrell, S., Slater, C.S. *An inductive approach to teaching courses in engineering*. American Society for Engineering Education Annual Conference & Exposition, 2003
[12] Dym, C., Agogino, A.M., Eris, O., Frey, D., Leifer, L.J. *Engineering Design Thinking, Teaching, and Learning*. Journal of Engineering Education, January edition, 2005.