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Applying Laser Cutting Techniques Through Horology for Teaching Effective STEM in Design and Technology

Lewis C.R. Jones and John R. Tyrer, Loughborough University, Wolfson School of Mechanical and Manufacturing Engineering

Nigel P. Zanker, Loughborough Design School

Abstract

This paper explores the pedagogy underpinning the use of laser manufacturing methods for the teaching of science, technology, engineering and mathematics (STEM) at key stage 3 design and technology. Clock making (horology) has been a popular project in design and technology (D&T) found in many schools, typically it focuses on aesthetical design elements. This paper describes a new project, which has been developed to enhance the STEM content of a horology project through advanced utilisation of laser cutting machinery. It allows pupils to produce their own products from self-made mechanical timing mechanisms. The central aim is to strengthen the application of the underlying technology of mechanisms and the manufacturing capability of laser cutting technology in D&T.

Trials with schools have shown success in gaining pupils' interest in STEM and provided feedback to improve the project. It has highlighted limits when delivering the engineering and maths content with teachers from non-technology backgrounds. The paper discusses this limitation through subject pedagogy, categorisation of teacher knowledge, and teaching effectiveness through experiential and problem-based learning approaches.

Key words

technology, teacher knowledge, problem-based learning, experiential learning, action research, STEM

Introduction

Conversation with teachers and the authors' anecdotal evidence has revealed that laser cutting technology is widely available and commonly used in secondary school design and technology (D&T) education. However there appears to be a lack of awareness of the applications of laser materials processing in industry, the potential for school practice or the safe and proper use of the equipment.

This paper questions and explores the use of resources that have been made available to teachers and, in doing so, challenges the design work for which lasers are most frequently used. Laser cutters in classrooms have been found by the authors to be generally used to produce the casing of products, which has greatly enhanced the quality of parts. However, there are other possibilities for utilisation of the machinery's capability. Examples of

current laser cutter use are found in *Designing*, published by the Design & Technology Association. Highlighted projects are using the laser to produce boxes (Berrill, 2011), or being used to produce jewellery (Elderton, 2012). Teachers' current knowledge of laser cutting has been used to increase the aesthetic characteristics of products at the expense of teaching, producing and using technology. Reports from the Office for Standards in Education, Children's Services and Skills, an independent regulator for schools in England, also highlight the need for teachers to improve upon their initial technological training and how lack of training and expertise meant teachers were not up to date with advanced technologies (Ofsted, 2008, 2011).

The *SET for success* report (Roberts, 2002) highlighted the importance of science, technology, engineering and mathematics (STEM) teaching to the economy. Design and technology offers many opportunities, as a contributory subject, for the teaching of STEM content through enabling technologies and practical application of skills (Johnsey, 2000; Roth, 2001; Sidawi, 2009). Schools have made large investments in computer-aided design (CAD) and computer-aided manufacture (CAM) technology in recent years. However, there are issues to the actual benefit to education, as the possibilities of the CAD/CAM technology may not be immediately realised. Innovative teaching practice has the potential to improve the use of existing, purchased technology in schools (Luckin et al, 2012). It contributes to developing pupils' practical skills to 'achieve a professional quality' (Ofsted, 2011). This paper includes an attempt to mapping out the pedagogic theory relevant to this technology problem by considering pupil learning styles and teacher knowledge.

Literature Review

The first section of the literature looks at different pedagogic theories suited to the delivery of STEM projects. They can be used to explain the value of features in the resources and to analyse problems identified in the case study. The resources created are intended to be interactive for the pupils and allow independent actions and thought.

Mosston's Spectrum of Teaching Styles (Mosston & Ashworth, 2002) can be used to order and structure the use of pedagogic theories. The spectrum organises teaching styles by the decision maker. It creates a continuum from teacher to pupil directed styles. This is

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Teaching Styles	Reproduction Styles					Production Styles					
	Command	Practice	Reciprocal	Self-check	Inclusion	Guided discovery	Convergent discovery	Divergent Discovery	Learner-designed	Learner-initiated	Self-Teaching
Who makes the decisions?	max					Teacher					min
	min					Pupil					max
Pedagogic Theories	Surface learning and information assimilation										Deep, experiential and problem based learning

Figure 1: Using Mosston's spectrum of teaching styles to classify suitable theories (Mosston & Ashworth, 2002, p. 10)

useful to this project where there is need to identify theories or teaching styles suitable for independent and interactive pupil work. The spectrum in Figure 1 is split into two clusters. Reproduction is concerned with the acquisition of basic skills and recollection of past and present knowledge. Production styles promote the discovery and engagement in new concepts.

The authors have used Mosston's spectrum to select theories, discussed below, to try and promote the use of production styles to get pupils to interact and discover

their own knowledge. Specific features and activities in the resource were created using these theories in an attempt to move beyond only a basic understanding of technology in D&T.

Surface learning is the term for when students are only taught to pass exams, whereas deep learning is what higher education and industry expect of pupils. Deep learning is the ability of a student to form their own conclusions and develop new ideas from what they are taught. The differences between surface learning and

deep learning are expressed in Table 1. Teachers, through their lessons, should promote a deep learning experience which builds on surface learning by pupils (Entwistle and Marton, 1984). The information in Table 1 was used to identify if deep learning was delivered in the created resources aimed to improve laser cutting technology education, and was used to avoid surface learning.

The practical elements of D&T enable opportunities for activities to develop deep learning through Kolb's (1984) 'experiential learning model'. Figure 2, shows the cycle of experiential learning where pupils begin with a concrete experience, to acquire basic skills, and then develop knowledge through their application.

Deep Approach, Intention to Understand

- Focus on 'what is signified' (e.g. authors argument)
- Relate and distinguish new ideas and previous knowledge
- Relate concepts to everyday experience
- Relate and distinguish evidence and argument
- Organise and structure content
- Internal Emphasis

Surface Approach, Intention to complete task requirements

- Focus on the 'signs' (e.g. the text itself)
- Focus on discrete elements
- Memorise information and procedures for assessments
- Unreflectively associate concepts and facts
- Fail to distinguish principles from evidence, new information from old
- Treat task as external imposition
- External emphasis

Table 1: Different approaches to learning (Ramsden, 1988, p. 19)

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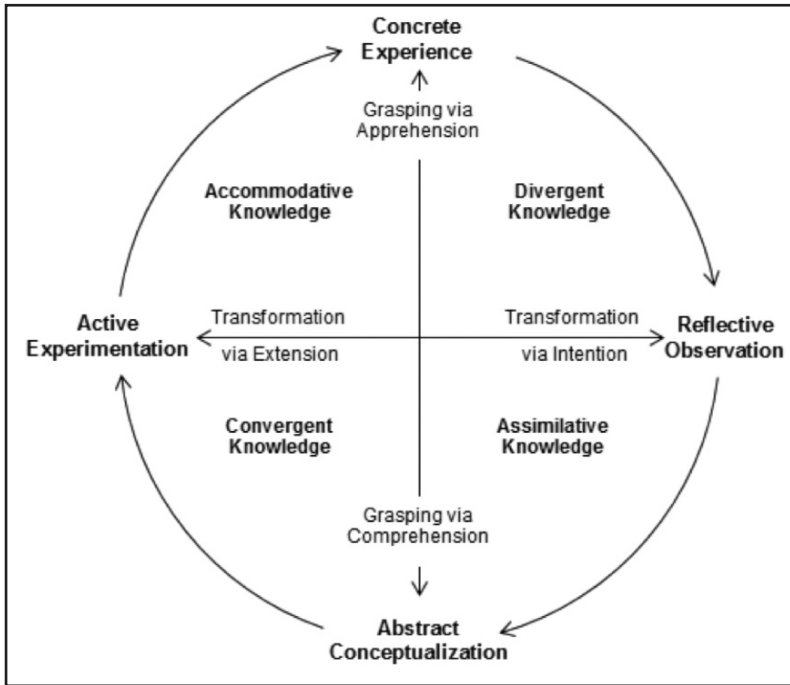


Figure 2: Structural dimensions underlying the process of experiential learning and the resulting basic knowledge forms (Kolb, 1984, p. 42)

Experiential learning is the outcome of reflection on experience. In comparison, a linear classroom experience of information interaction is through teacher instruction where pupils are first taught abstractions (Keeton, 1976). Factors that can enhance experiential learning are the teacher, the learner or a third party. (Fowler, 2007) Resources created should be designed to guide and improve the experiential learning process. A resource may be created that is not just for practicing design, manufacturing or assembly skills, but to enable experiential investigation of the design features to facilitate further learning.

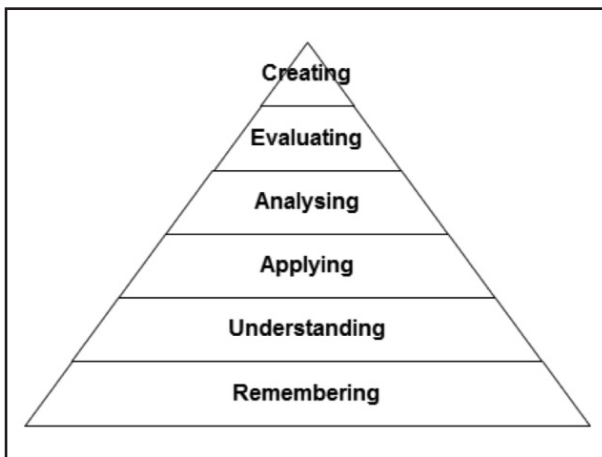


Figure 3: Revised taxonomy (Anderson & Krathwohl, 2001)

Williams et al, (2008) describe how the characteristic features of problem based learning (PBL) are suited to the design process of technology education. PBL activities include promoting observational skills by using as many senses as possible, using simulations or experience to simulate reality, student collaboration, student directed learning, independent study and getting students to reflect on their learning process. Lou et al, (2011) recommend integrating the use of PBL strategies with a STEM project, because these strategies can have a significant effect on STEM integrated knowledge learning.

The original taxonomy of educational objectives developed by Bloom in 1956, describes in the cognitive domain, a six level hierarchy of thinking. Anderson and Krathwohl (2001) produced a revised version of the taxonomy which made several modifications to the terminology, structure and emphasis. Figure 3 shows

the taxonomy, revised in verb form (ie through activity), making it a helpful tool for teachers to use in writing objectives. The hierarchy describes the levels of learning that students can progress through. Students pass from the lower levels to the top, and each level subsumes the previous one. However, their starting point may be at any level, and levels may be omitted.

The taxonomy can be used to plan teaching activities (Ferguson, 2002; Pankajam, 2005) and to assess the level of cognition (thinking) to which students perform. This can be applied to features of resources being used and sub-activities to facilitate pupils' analytical, evaluative and creative behaviours.

Two models of teacher knowledge have been included to be used to analyse the behaviour of the teachers delivering the content and using the resources. Shulman (1986, 1987) categorised types of teacher knowledge as:

- Content knowledge,
- General pedagogical knowledge,
- Curriculum knowledge,
- Pedagogical content knowledge,
- Knowledge of learners and their characteristics,
- Knowledge of educational contexts,
- Knowledge of educational ends.

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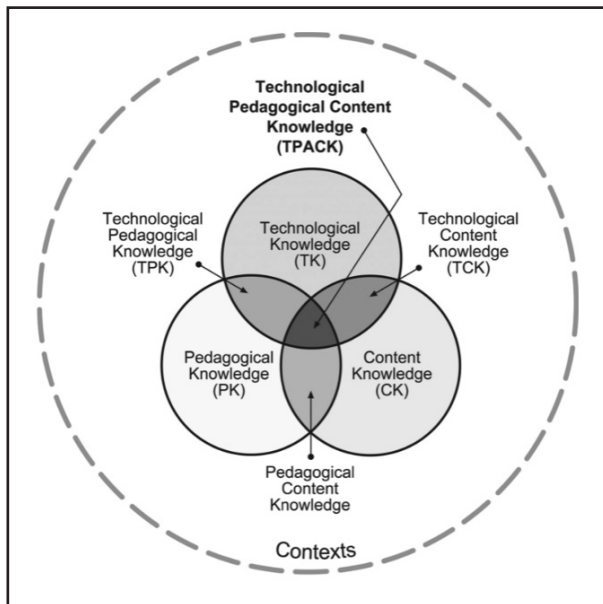


Figure 4: The TPACK framework and its knowledge components.

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The most significant of Shulman's categories for this project are content knowledge and pedagogical content knowledge (PCK), which identify the knowledge required for transferring teachers' knowledge into their teaching. Mishra and Koehler (2006) developed their technological pedagogical content knowledge (TPACK) framework, Figure 4, by introducing technological knowledge to Shulman's model. The TPACK framework is the interaction between the three primary forms of knowledge: Content (CK),

Pedagogy (PK), and Technology (TK). The primary knowledge forms can be combined to create new knowledge forms. The TPACK knowledge form goes beyond the three individual primary forms creating the basis for effective teaching with technology (Koehler & Mishra, 2009).

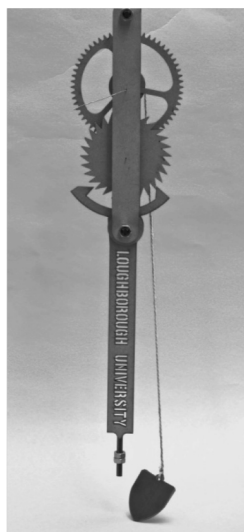


Figure 5: Laser made mechanical timer

The application of the TPACK framework to D&T is interesting as the use and understanding of technology is critical to the subject. Mishra and Koehler identified how technological knowledge is currently considered as a separate knowledge domain to pedagogic

related knowledge. They analyse how teachers are exposed and trained in a context free environment to operate machinery involving new technologies.

Without developing technological and pedagogical content knowledge, teachers may not teach technology as effectively through its application to projects. This may be a contributory factor to explain the authors' observations of the under-utilisation of laser cutting technology in schools. Polly (2011) shows how Mishra and Koehler's TPACK framework can be used to grow teachers' technological knowledge, technological pedagogical knowledge and content knowledge.

Project Produced

The project that has been developed to teach STEM in D&T curriculum classes is a laser cutting project where pupils make a mechanical timer. Intended as a Key Stage 3 project the assembled base timer is shown in Figure 5. This is the minimum expected outcome as pupils will be able to adapt and produce their own products from this mechanism.

The project introduces novel use of laser cutters in schools, advancing the technology to its full capability and using it to produce components for a STEM project. Figure 6 shows the computer aided design (CAD) of the mechanism which reveals that all the functional components, such as gears are also manufactured on the laser cutter. The design makes use of the precision and detail that can be achieved by computer aided manufacture (CAM). Pupils can produce their own functional mechanical components at a fraction of the cost and time of traditional manufacture, bringing engineering concepts to D&T.

The resources that have been created for this project, and provided to teachers during the trial are 2D CAD data, Figure 6, and assembly instruction manuals, Figure 7. The CAD files are available in Techsoft 2D Design file format as this is the 2D CAD software taught and used in secondary schools. The instruction manual provides a step-by-step picture guide for pupils of how to assemble all the parts once they have been laser cut.

For schools to be able to adopt the laser made mechanical project and run it in their own classroom teachers must be able to do it with the facilities they have available. The laser made mechanical project has been developed with an appreciation of the modern D&T classroom environment. The design has been developed from evolving horological work at Loughborough University (Jones et al, 2012).

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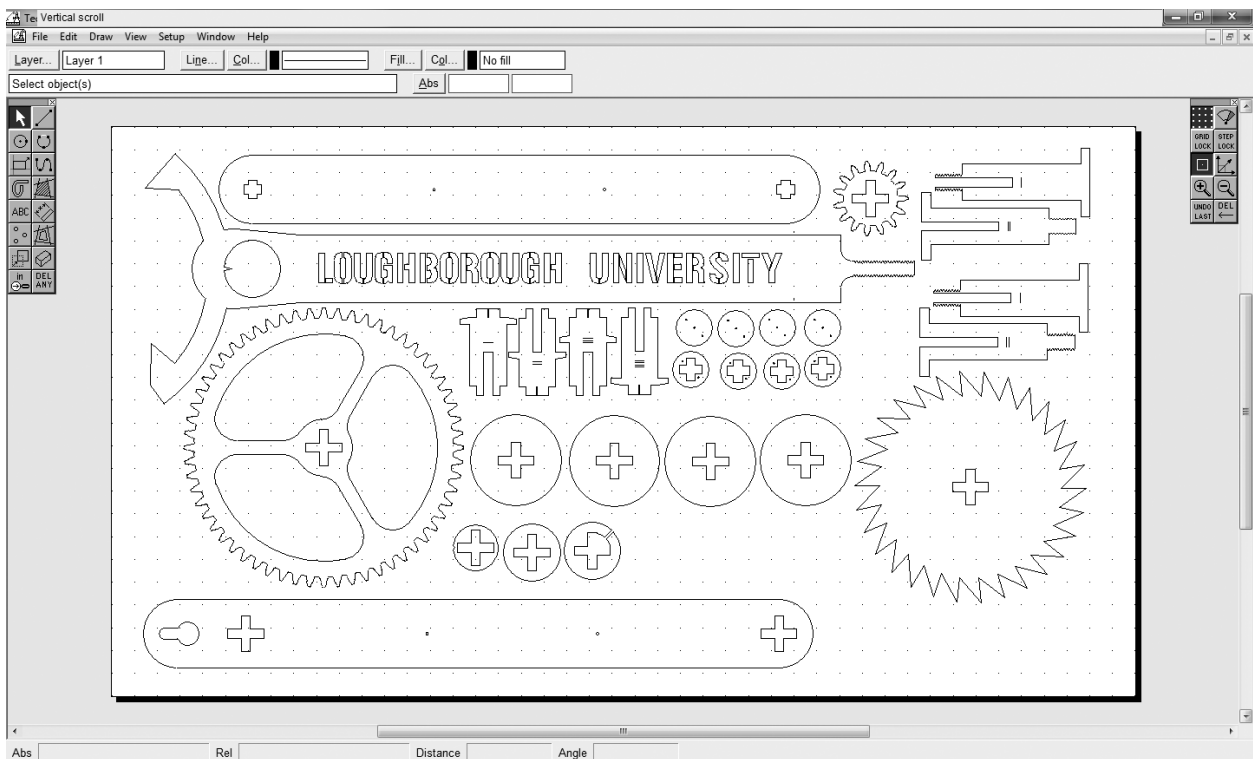


Figure 6: Timer cutting pattern in school CAD software

Materials have been selected to be affordable and typically already available in schools. Thicknesses are suitable for lower-power school laser cutters while still maintaining performance. Machined bushes and roller bearing units have been removed from the laser made clock designs and have been replaced with paperclip or panel pins needle bearings. These are significantly cheaper and easier to produce but performance has been maintained through laser processing techniques. The corresponding laser drilled holes in MDF have large internal carbon deposits from the vapourisation process. This acts as a dry lubricant aiding bearing performance. The amount of required parts in the design has been minimised. This reduces assembly time, material costs and cutting time. This involves creative features such as the combination of pendulum and escapement pallets which removes the need for multiple bearing parts, separate pendulum detachment and the crutch mechanism. Although the removal of these parts will reduce the accuracy of the pendulum motion it will still give satisfactory performance and the significant reduction in complexity will benefit the students. Laser cutting of the parts allows for parts to be efficiently nested into a smaller sheet of material and the supplied CAD files only require a small 450x250mm piece of MDF suitable for school laser cutters and school budgets. The slot and pin methods are non-permanent allowing disassembly to correct any pupil mistakes. It also does not require the use

of adhesives removing the risk of toxic chemical use in lessons. The incorporated thread forms on parts of the clock are a unique feature of this design, made possible by the small kerf width of laser cutting. They allow standard nuts to be used for fixing and for pendulum centre of gravity adjustment. The pendulum adjuster is a really simple mechanism feature that provides classroom experimental potential.

The CAD files which are provided to the teacher are the starting point for a STEM advanced project. The CAD files are an innovative kit of parts, which incorporate the many design features highlighted. However the project is not intended to be a simple cut and assemble task. Pupils should use their CAD skills to customise, modify and implement new design features. The basic kit allows pupils to quickly produce the timing mechanism, which they can incorporate into their design work. The designs supplied will show pupils the advanced capability of the technology with the teacher explaining the fundamentals of laser cutting including health and safety and how laser cutting is used in industry.

The intention of the design and instructions was to allow pupils to construct a complex mechanism easily. This would enable pupils to be able to rapidly progress to investigating the mechanism to learn about it. There were

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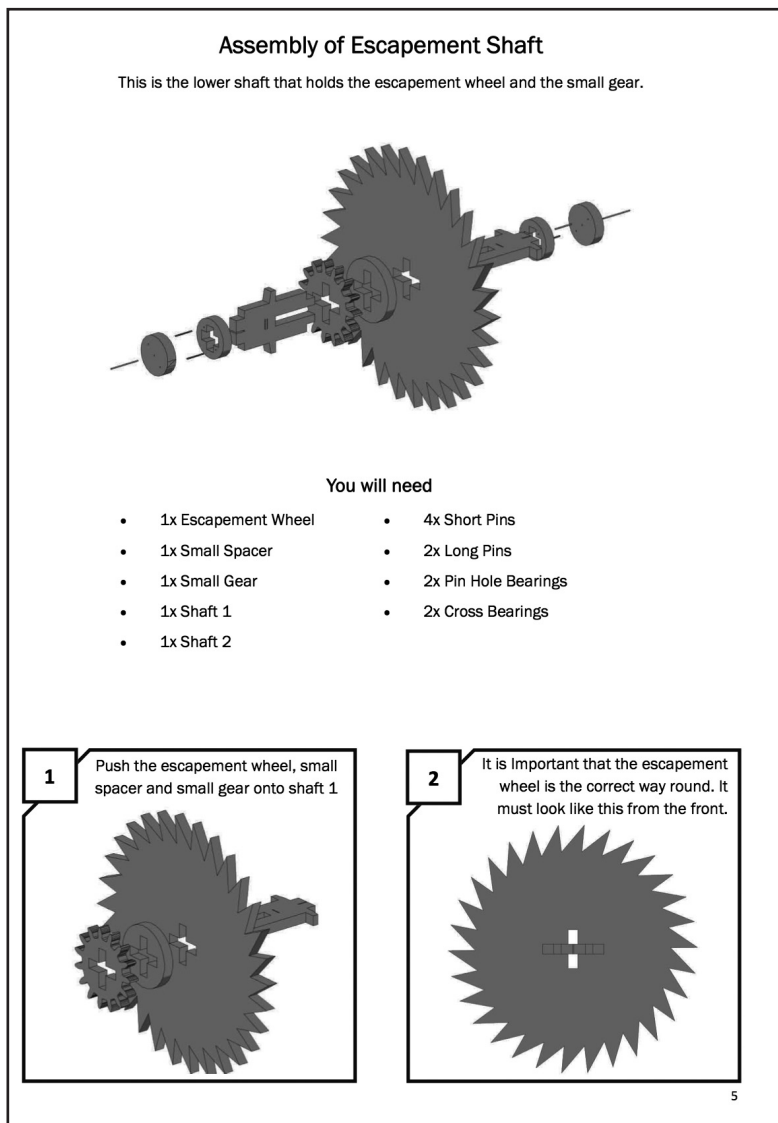


Figure 7: Example page of assembly instruction manual

learning activities incorporated into the design. Such as getting pupils to identify and explain, using the correct technical vocabulary, the different components within the mechanism. Also for pupils to calculate appropriate gear ratios to alter the running of the mechanism to a desired time period and learning about gears through experimentation. As well as using 2D CAD to customise the design and to make suitable modifications for laser processing. Additionally getting pupils to use their mathematical and physics knowledge to explain how the system functions and experimentally test their theories to improve their products.

One advanced feature included in the design is the adjustable pendulum. This can be simply made with laser

cutting technology and it allows pupils to undertake an experimentation activity. The mechanism will not run exactly on time when first made, it requires pupils to analyse how changing the effective length of the pendulum alters the rate of the mechanism. The opportunity exists for teachers to run this as a scientific experiment which would allow pupils to make a hypothesis about how the mechanism works from their physics knowledge and then test it. This brings in strong cross-curricular links, creates many learning opportunities and shows the benefits of using maths and science in design.

Results of Project Testing

The testing of the mechanical timer project and its resources was done predominantly through an action research methodology with Postgraduate Certificate in Education (PGCE) D&T trainees. Data was generated through focus group interviews with PGCE student groups, unstructured interviews with PGCEs and their supervising mentors before the project began, notes taken in final lesson observations, a short questionnaire for pupils and closing interviews with the PGCEs students who delivered the project. Table 2 shows the schedule of the different data generation activities used to produce the case studies.

Focus Group Session 1

Five PGCE trainees were selected, to trial the timer resource in their teaching placement schools. Three of the group had used a laser cutter previously but all reported being unfamiliar with the technology of a laser cutter. All five trainees were given a set to build and the instruction pack. There were issues with following the instructions, leading to mistakes. Some points were unclear and amendments were made to the instruction manual. Once the instructions were followed and the diagrams used, all trainees completed the timer assembly. The trainees were taught how to investigate the timer to understand how it works, the type of activity expected to be performed in schools. Through this the trainees became more comfortable with the mechanism.

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Activity	Date (2012)
Focus group with the five PGCE students who would run the projects in their placement school. PGCEs were instructed on how to produce and use the mechanism.	Mid February
Focus group with entire class of 18 PGCE students. The five running the project taught the others and then the whole group discussed using the mechanism as a project.	Late February
School pre-activity unstructured interviews with PGCE and mentor to discuss the strategy for implementing the project in their school and identify any issues.	Late April
Correspondence with PGCE students during the project.	Mid May
School final lesson observation and pupil questionnaire containing open and closed questions to gather data about how pupils found the project and what knowledge they gained from activities they undertook.	Late May
Group semi-structured interview and discussion with PGCE students after project has been completed.	Late May

Table 2: Project schedule for data collection activities

Focus Group Session 2

To assist the selected five PGCE trainees in using the resource in schools they taught thirteen other PGCE trainees how to assemble and investigate the mechanism in the second focus group. There were similar problems to the first session where people did not follow the instructions; this issue was reported by those instructing. Trainees with more technically able instructors in this session were able to perform the analysis tasks, and showed learning of the mechanism through experimentation. Trainees from non-mechanical product design backgrounds admitted that they struggled with the core physics behind the design. When asked similar probing questions about how the mechanism worked they were not able to propose theories like the more able group. This highlights the issues with the different abilities and backgrounds of trainees, as they develop content knowledge in preparation to become teachers in schools. The group of trainees were very focused on how to assemble the mechanism and the issues that pupils in schools would have in building it. The discussion was able to highlight areas of the design that could be changed to better suit schools.

Schools Case Study

The PGCE trainees used the resources in their own lessons on one of their teaching practices. Each trainee

has a school mentor to supervise the project. The mentors and the trainees were provided with the CAD files and instruction manuals for the design and were given permission to modify the files to suit their needs if required. The resource had been developed to be used as a curriculum project aimed at year 9. Each school was given freedom to utilise the resource as they wished.

School 1

The resource was used in a three lesson extra-curricular, after-school activity for year 9 gifted and talented (G&T) pupils. The PGCE trainees and the school mentor had many reservations about being able to integrate it into the curriculum as it was currently presented. They felt that product design aspects of the project were not a significant development from their school's existing year 7 and year 8 CAD and laser cutting projects. However, the school considered the level of STEM learning and assembly required was suitable for only the higher ability year 9 pupils and so could not be delivered to a whole class. The school was concerned that the resource was not developed enough for curriculum lessons and that pupils may find the subject matter uninteresting.

Twelve G&T pupils were approached but only four accepted. The school developed additional activities to deliver the different teaching areas, using their laser cutter

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to produce more gears from additional files provided. Gear theory was taught through experimentation with example gears and supported with existing activity sheets sourced from the internet. The mentor expressed the opportunity to replace this manual experimentation with software simulation, as the school had unused advanced CAD software.

The two pupils in the final activity were shown the laser cutter in operation and there was a discussion on suitable materials with the trainees, but no detailed information about industrial use, health and safety or technology. The trainees did not prepare the same amount of work that would have been done for a normal lesson. There was confusion with cutting the parts from the correct files provided this shows lack of trainee knowledge and familiarity with the design. Trainees struggled to implement design corrections identified in the focus groups. The pupils were able to investigate and produce the timer by following the step-by-step guide. Pupils compared their assembly to the pictures to confirm if it was correct. The trainees did not perform any of the investigation activities with the pupils once the assembly was complete.

School 2

The resource was used in a twelve lesson curriculum project for year 8 pupils. The PGCE trainee and the mentor were enthusiastic about incorporating the mechanism into a laser cutting project as they were aware it was an under-utilised resource in the department. The plan to integrate the mechanism into a class project covered many of the teaching aspects that were desired. There was sufficient time throughout all the sessions to investigate both the mechanism and the engineering elements. The teacher gave the pupils a design problem to solve. The pupils worked in groups to build a new timing product for each school department to use. This required pupils to incorporate the mechanisms into a unique product for their end user.

The trainee and mentor successfully integrated the timer resource into the standard design process. Project activities included design briefs and specifications with explicit terminology, investigating different materials and incorporating different processes into their design, such as the use of textiles for aesthetic features. There were also specific lessons and activities for teaching gears.

Pupils were given pre-cut kits of parts customised by the trainee, with each group using a different material. Assembly of the mechanism was spread over several lessons to allow time for problem solving and aesthetic design concepts. Before the final lesson the groups had

already investigated and evaluated their mechanisms. It was reported by the teacher that the pupils had really excelled and been interested in the mechanism design. An important discovery is that the mentor stated that the project had engaged pupils that the mentor normally and personally perceives less able or not interested in D&T.

The final lesson was a set of group presentations by the pupils. The groups were all able to explain how the mechanism worked in relation to forces, gear ratios and pendulum function with the correct terminology. Some groups had problems assembling the mechanism but they were able to identify the faults. The groups had however not been instructed by the trainee or teacher to investigate the relationship between pendulum length and timer rate and the pupils knowledge of laser cutting was limited to material choice.

The mentor had reported unfamiliarity with laser cutting technology and their lower power laser system prevented all pupils from individually cutting a mechanism, and experiencing the technology, as the machine at this school was too slow for use in lessons. The PGCE student did successfully produce the mechanisms in various materials for the pupils, and also used the cutter to produce teaching aids for gear theory.

School 3

The resource was used in a ten lesson curriculum project for year 9 pupils. The PGCE trainee at this school was not comfortable with the technology and engineering aspects of the resource, and had reported this to the researcher. The school had a new laser cutter but no projects or experience, the member of staff that had used the previous equipment had left.

The school's existing projects were more aesthetically focused and the mentor saw this project as an opportunity to integrate the mechanism into teaching. The mentor's main reservation with the resource was the lack of differentiation as it was felt that it was currently only targeted to the more able pupils, the mentor and trainee were also unsure of what to incorporate the mechanism into as the resource was not already provided with product design activities.

During the final lesson at this school, the pupils were supposed to be evaluating the mechanisms they had made. However due to technical difficulties, manufacture of the cases had been delayed to the last session. The pupils were unable to complete the manufacture of their designs and were unable to test and evaluate the mechanism within the initially planned 10 lessons. They

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had already manufactured and assembled the sub-components in other lessons and so had gained exposure to elements of the design. There were also fully constructed mechanisms, made by the trainee, to be used for discussion throughout the project. Pupils did not fully understand the timer mechanism they were building or the manufacturing process. They were unaware of the terminology and could not explain how the mechanism they had previously seen worked.

Findings and Discussion

General feedback from the PGCE focus groups was positive, there was little objection to the idea of using a laser cut timer in D&T. Discussions at the end of the focus group sessions revealed there was a lot of variation in the trainee's content (subject) knowledge, with many in the group having low technological knowledge relating to the engineering elements of the design and the use of laser cutting machinery. The final discussion, led by one of the PGCE course teachers, was supposed to develop pedagogical knowledge with the resource by formulating ways to use the resource but as they did not have the content knowledge to understand what would be the important STEM areas to teach the group was focused on health, safety and practicality issues.

Although everyone was able to assemble their mechanism, some of those assembling the mechanism became dependant on the teacher. They stopped reading their instruction guide and copied the teacher. This is evidence of surface learning techniques. Deeper learning would be promoted if pupils were allowed to investigate

and assemble the mechanisms for themselves, with minimal teacher intervention.

The method of experiential learning was successfully demonstrated in the second focus group where learners performed the experimentation activity to explore the relationship between pendulum length and clock rate, and also the function of individual components in the mechanism. The cycle of the experiential learning model was; experimenting with the mechanism, apprehending from experience, reflecting and discussing the proposed theory with others and retesting their theory and finally comprehending how the mechanism works.

Analysing the results of the case study from a teacher knowledge perspective revealed many of the problems encountered and explained the results. Before the teaching project, the trainee and mentor from school 1 were the most technically able and were confident in delivering the content from the school's past experience of teaching engineering and use of laser cutters; In contrast with schools 2 and 3 who both reported unfamiliarity with the STEM content and the use of laser cutters before the project. This shows how the teacher's own perceptions of having to teach technology in D&T can take them out of their comfort zone. Although school 1 had the best resources and was the most technically capable, having existing long running laser cutting projects, they were resistant to delivering the more advanced features that this project offered. Their laser cutter was being used to produce many different shape cutting projects, with which they were comfortable with. This shows that advanced

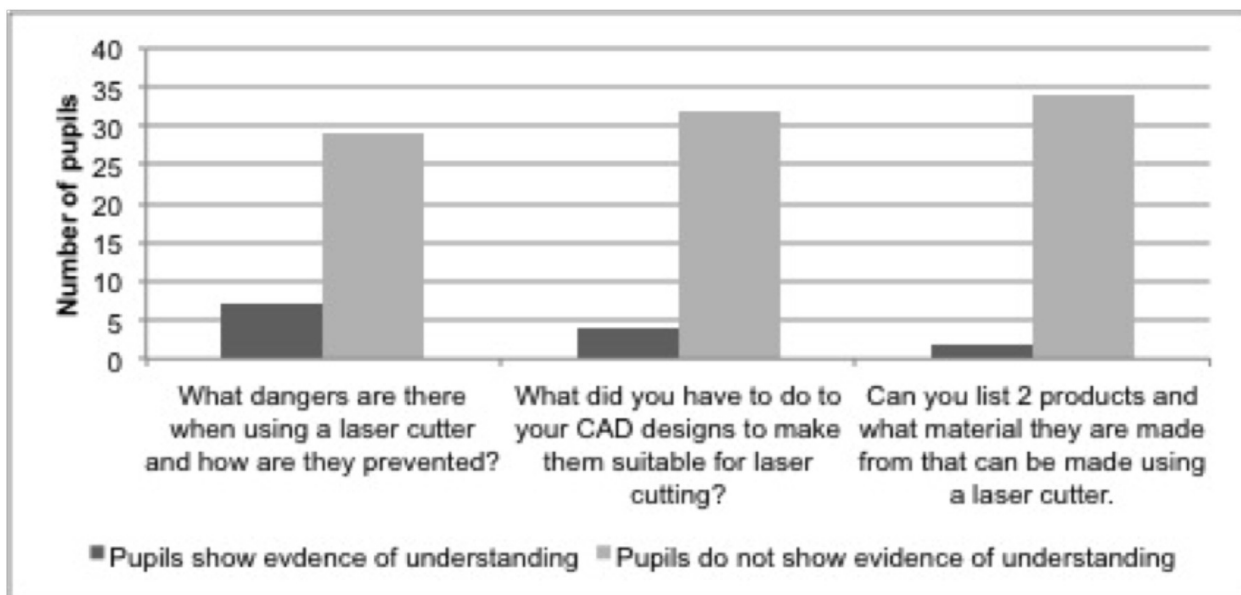


Figure 8. Laser cutting results from pupil questionnaires, n=36

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utilisation of this equipment may be limited as a consequence of insufficient technological knowledge, even in schools that are frequently using the technology.

In none of the schools were the pupils made to perform the separate experimentation activity with the timer. This activity was shown to the trainees, during the focus groups, as a way to incorporate science investigation into the lesson. In the final debriefing with the trainees this was discussed with them. The trainees thought that that teaching pupils about laser technology and understanding the mechanism may not be relevant in D&T and is more suited to the physics classroom. This again highlights an issue with technological knowledge but it is also a major issue to the delivery of technical content in D&T. This could be clear evidence that teachers from a non-STEM background have a substantial difficulty not just delivering the content but understanding its importance. The trainees themselves were unfamiliar with the technology and were unable to answer pupil questions on the workings of laser cutters. Furthermore, they were unable to deliver relevant content to pupils about laser cutters, as evident from pupils' questionnaire results in Figure 8. This is the type of behaviour that the resource is trying to address as it is aiming to encourage the teaching of technology in D&T.

The fourth school withdrew from the research at an early stage. This was because the trainees were unable to incorporate the resources given into a lesson plan to deliver to pupils. This was an unexpected result as the trainee at this school was an engineering graduate so, therefore, had the technical knowledge but was unable to develop it with the necessary pedagogical knowledge to deliver the content. This is a clear example of the TPACK framework where it is not enough to just understand the abstract technological knowledge; teachers must develop a combined technological pedagogical content knowledge to be able to use such resources for teaching.

There were observed issues with surface learning, for example the pupils' limited or incorrect use of technical names of the components which shows incomplete understanding of how the engineering and technology worked. This was evident in school 3 where the pupils could not relate the theory to their mechanism. An understanding of how the mechanism worked, i.e. deep learning, not just the names of components, were observed in the final pupil presentations of school 2. The difference in pupils knowledge is related the use of experiential and problem based learning techniques. Schools 1 and 2 produced experiential learning gear activities to teach gear design to pupils. Through this, the

pupils could investigate different gear ratios to understand how they work, they could then reflect on their experience when learning the mathematics of gears. The experiential method of learning this worked well in these two schools and pupils were able to demonstrate their working knowledge of gears at the end of their projects. The trainees at schools 1 and 2 also built demonstration timers so that pupils could experience the mechanism at the beginning of the project; this appeared to help pupils understand the mechanism so they could create their own.

Pupils at school 3 were taught gear theory first before trying to design their own gear-based mechanisms and did not use an experiential learning method. Observations at the end of the project showed that pupils at school 3 struggled to explain how the mechanism worked and could not relate the gear theory to the design.

Features of a problem based learning strategy were apparent in school 2. The teacher had incorporated the mechanism into a product design problem for the pupils. The pupils worked in groups to analyse and solve problems with incorporating the mechanism into their product. The lesson plans from all three schools reveal that STEM content was delivered in specific lessons at the beginning of the project, and was not applied elsewhere during the project. It was thought that problem based learning, incorporating the mechanism into a product, would aid the integration of STEM throughout the project. Although guidance on how to deliver problem based learning, or which lessons should specifically deliver STEM content was not given to the trainees. This shows that direction for teachers on problem based learning and STEM lessons needs to be introduced to the existing resources.

There was no evidence from the lesson plans, observations or post-activity interviews that the activities intended for the mechanism to achieve the higher the cognitive levels of the taxonomy of educational objectives were achieved or encouraged by the teachers. The schools showed evidence of remembering and understanding the gear mechanisms and pupils were able to apply their knowledge to gear calculations. The creative aspects of the project were planned as opportunities for pupils to develop new mechanism features and apply their own ideas in incorporating the mechanism into a product. The experimentation activity was also designed to get pupils to analyse and evaluate the mechanism, applying their science and mathematics knowledge to design. The features of the resource intended to facilitate the higher levels of the taxonomy were not clear enough for the

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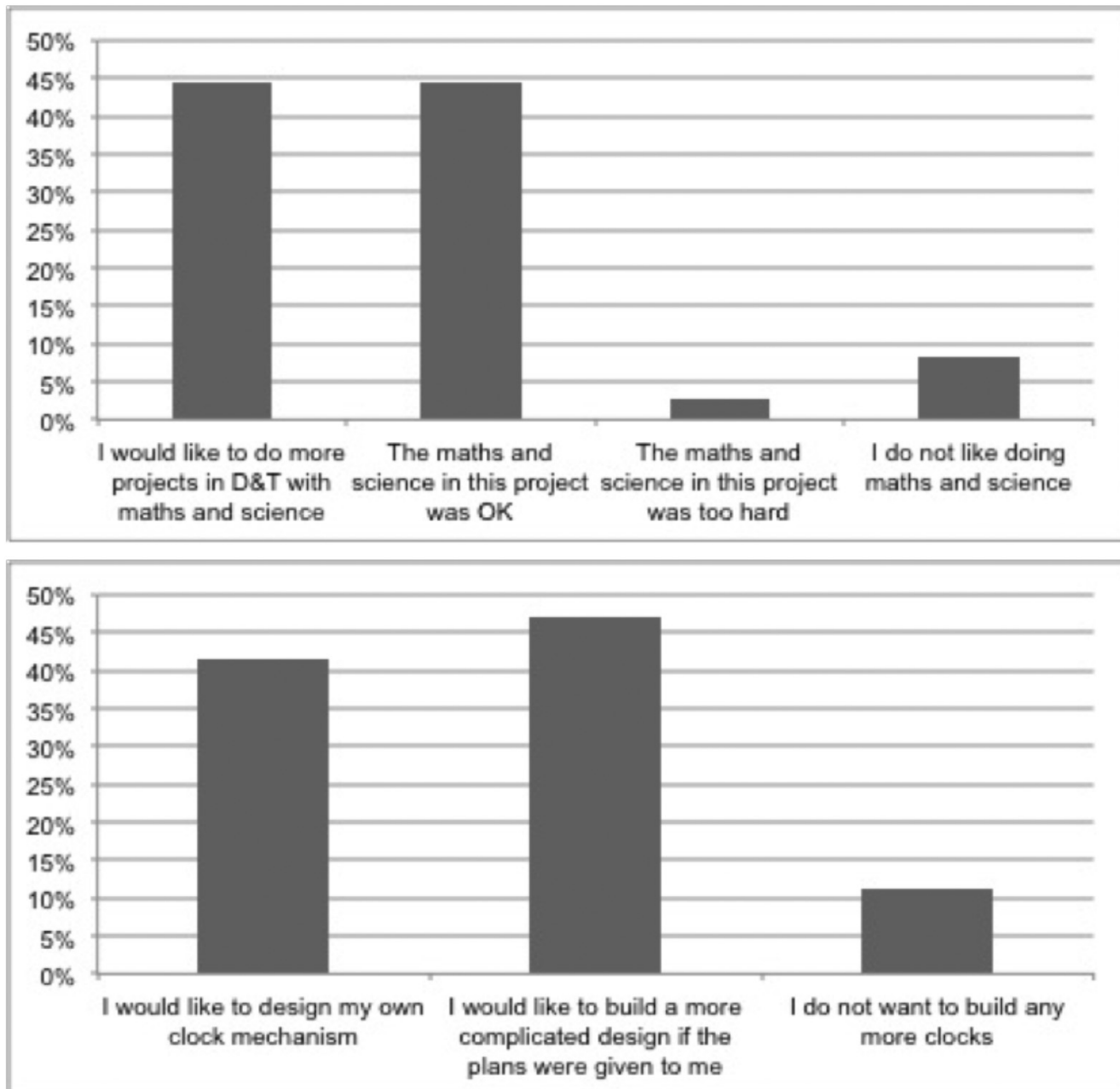


Figure 9 : Pupil satisfaction results from questionnaires, n=36

teachers and the trainees reported were not confident in delivering the exercises and content.

Pupil satisfaction results from the questionnaire are shown in Figure 9. They reveal how positive the responses from pupils were in relation to the STEM content and the horology project. This is a very successful initial result and indicates the expected level of enthusiasm pupils have for a STEM project as well as the success of using a complex theme such as horology to deliver it. The result opposes the teachers initial reporting that pupils would not be attracted to such a technology driven project.

There were other factors affecting the results of the schools. The pupils in case study 3 were in an unexpected situation where they had already selected their GCSE options before undertaking the timer project. It was stated by their teacher that the majority of the class had selected not to continue with D&T at GCSE. This has two effects on the results of the project. The pupils are more likely to be disinterested in learning the subject as they know it does not matter to them anymore, resulting in a poorer uptake; this could account for the surface learning results of the pupils in school 3. As they have already selected their GCSE options the project cannot encourage pupils to aim

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for a STEM career and cannot influence pupils to continue with a STEM education.

Case study 1 observes the resources being delivered in an afterschool club, limited to the G&T pupils. The school made this decision as they felt that the content of the project was beyond the capability of a full year 9 class. Due to the successful implementation of the project with a full year 8 class, school case study 2, the content is suitable for years 8 or 9.

Conclusions

In order to enable this small trial there has been a substantial amount of work in the preparation of the materials in a form which is accessible and suitable for teachers and pupils to use. It was essential to produce a design of a suitable quality to introduce the intended concepts in a creative and challenging way to pupils. The design was carefully crafted not to overshoot the ability of this age group of pupils. This was something that may have happened if using examples of traditional mechanical clockwork. Likewise, the capability of school equipment and budgetary constraints were considered from the beginning. There was a significant amount of work in the design to ensure that it was robust enough to be successful. If the level of work was reduced then it was thought that it would not allow pupils to build a functional product that they could appreciate. The detail included in the mechanism allowed for future development of new activities, as there were many more potential areas for pupils to investigate.

The results in Figure 8 demonstrate that at this age group the pupils were unaware of the details in using this technology and this showed that pupils would not have intuitively done these types of activities. However, Figure 9 shows that they did enjoy the content. It is encouraging that pupils do want this level of complexity in a project. The results also revealed the need for more teacher focused resources to help fill the gaps in technological knowledge and pedagogic content knowledge relating to the application of laser cutters and mechanical systems. The question we have attempted to answer is, could we inspire pupils who don't understand laser cutting technology to do more with the equipment they have available? Although this was a small trial of the project the research demonstrated that pupils in year 8 were responsive to STEM projects that use appropriate delivery

and experiential teaching methods. It is hoped that targeting this age group will improve the number of students continuing with STEM education at GCSE level and beyond. The teachers' limitations affecting the delivery of specific content in the project have been identified and can be addressed with future developments and additional resources.

There is plenty of opportunity to expand the project and introduce other schemes of work to increase the teaching of technical content following the same pupil learning methods. Further work includes the formation of an online delivery method for the resources allowing pupils to directly access projects to improve independent learning and teacher facilitation as well as the creation of a continuing professional development course for teachers in laser manufacturing to train them in unfamiliar content. Additional teaching resources should include guides to the module and its content, resource based activities and more explicitly promote experiential and problem based learning actions.

Subsequent projects to be developed will investigate the other areas associated with laser cutting. For example, introducing advanced concepts such as parametric CAD, to exploit more functionality, and to investigate manufacturing of textile components using lasers to create footwear. Eventually, the aim is to have a series of projects that develops pupils' knowledge in STEM and the creative/practical skills associated with laser technology as they progress through education.

This project was relatively small, with three school participants, but the foundations have now been created to be able to further investigate these projects and their impact in schools. It is now believed that the project can be expanded and studied on a larger scale. The teaching materials created from this research are available at clocks.lboro.ac.uk. Feedback is welcomed.

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l.jones@lboro.ac.uk

j.r.tyrer@lboro.ac.uk

n.p.zanker@lboro.ac.uk