

Can tinkering benefit pupils' learning?

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Abstract

The current National Curriculum for design and technology specifies that pupils use an iterative design process, work collaboratively and explore new technologies. Therefore, teachers must plan lessons to incorporate these strategies in order to promote pupils' progress sufficiently.

This study focuses on a key stage 3 textiles class in a secondary school where an e-textiles lesson was written into the scheme of learning in order to implement the new initiatives. Tinkering was trialled as a teaching strategy and its success was measured by the progression of pupils' knowledge.

The pupils were set a series of challenges to guide their exploration of electronic textiles components, working iteratively to solve the problem of high demand. The results revealed that pupils' knowledge did increase following the tinkering lesson. Therefore, these results may facilitate improvements in future teaching strategies to inform practice and meet the government requirements.

Key words

Design and Technology; textiles; e-textiles; electronic kits; iterative design; collaboration; tinkering; guided discovery learning; creativity; secondary school.

Introduction

Secondary design and technology (D&T) education, in England, requires pupils to find solutions to real-world problems through collaboration and iteration. These approaches aim to develop pupils' thinking and prepare them for the technological advances of the modern world. Initial observations, of D&T teaching, identified a heavy emphasis on teacher led tasks, using direct instruction and leaving little freedom for pupils to be creative. This study was designed to determine if pupils could gain knowledge by more student-centred approaches, including tinkering. This study was conducted to inform teaching strategies and improve practice for a trainee teacher working in an English secondary D&T department.

Literature Review

The Oxford dictionary (2016) defines tinkering as a means of repairing something in a casual manner. However, under new English National Curriculum guidelines this word could find itself a new relevance, forging links with constructivist learning theory and discovery-based teaching strategies the term 'tinkering' is infiltrating into educational 'speak'. Doorley (2016), founder of the online maker community Tinker-lab, acknowledges the significance of tinkering in education, defining a tinkerer as "one who experiments with materials and ideas to fully understand their capacities, and who further iterates on their learning to find better solutions to current problems." There are quite a few literature studies on guided discovery teaching methods and constructivist learning theories; studies on tinkering however, are rare to find. This study aims to examine tinkering as a teaching strategy in order to inform teaching practice to benefit pupils' learning and meet the current English National

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Curriculum guidelines for design and technology. The success will be measured by the effect of tinkering on pupils' knowledge.

Choulerton (2015, p. 7) highlighted concerns that the key stage 3 (KS3) curriculum is currently offering "very heavily guided making tasks with very limited opportunities to design 3D and very few opportunities to engage in an iterative design process," suggesting little has changed following the 2011 Ofsted report into design and technology. Ofsted (2011, p. 25) reported that a number of lessons at KS3 required "all students to follow instructions with almost all decisions about designing and making taken by the teacher." Similarly, observations at my professional practice placement one highlighted frequent use of behaviourist teaching strategies, such as direct instruction to lead pupils systematically through a linear design process and ensure a positive outcome. These tasks were sometimes of low challenge and largely teacher centred, resulting in pupils adopting a passive approach to learning and failing to acknowledge the purpose of each task.

Through informal questioning of a number of teachers I found that they perceived the English National Curriculum to require the use of modern technology, which is expensive to run and maintain, validating reasons for a direct instruction approach. As school budgets are limited the department relies on parental contributions to subsidise the materials. This results in pressure for pupils to create a quality product to take home due to their contribution towards the provisions. Heavily guided tasks support this outcome. Additionally, group work is limited as pupils work individually on projects to take home. Barlex (see Hardy and Davies 2015, p. 209) rejects conceptions that pupils must create a product to take home, suggesting four alternate types of activity for D&T lessons: Making without designing; Designing without making; Designing and making; Exploring the technology and society relationship. This model allows for a wider variety of focused tasks without such a need for a final product to be made. Group work could possibly require fewer resources, for example one kit between four pupils, thereby reducing department spending. Additionally, exploring technology without making a final product could enable materials to be reused with other classes, removing the need for parental contributions.

Another reason for delivering direct instructions was pupils' motivation with regard to failure. The teachers questioned were concerned pupils could lose interest in the subject if their design ideas didn't work, which might have a negative effect on GCSE take-up at key stage 4 (KS4). Wood-Griffiths, Lawson and Winson (2015, p. 138) support this view, recognising that KS3 teachers have the chance to "capture pupils' interest in learning about textiles so it is important that the pupils enjoy the work." However, they continue to argue that this enjoyment must be balanced by the development of knowledge. Cowell (2015, p. 95) favours guided discovery promoting a motivational outlook on failure, encouraging pupils to "think of failure as a start point – when something does not work the fun begins; become a detective and try to track down the reason why." This fail-forward mind-set supports the theory of tinkering and iteration. If the task goes right the first time pupils are merely learning to follow instructions. Could tinkering support the development of knowledge without the need for direct instruction?

Interestingly, this is contrary to the philosophy of Christodoulou (2014) who favours the use of direct instruction, imagining that discovery based teaching lets pupils down, bypassing the facts, leaving gaps in their knowledge. More convincingly Lowe (2013, p331) explains how rote learnt facts form a foundation for the mastering of skills, "such facts are necessary for advanced work – they contribute to the sub-routines that allow us to function at a higher level." For example, establishing correct spellings through direct instruction could enable

pupils to communicate their design ideas more effectively through annotations. However, these strategies may result in passive learning, where pupils are expected to absorb knowledge rather than doing the task themselves. Cowley (2005, p. 70) advocates a balanced approach to teaching strategies "although open-ended questions and situations are great for learning creatively, there will be times when it is easier or more sensible to simply pass on the information that is needed." If every lesson had guided discovery aspect pupils could find themselves re-inventing the wheel. Lowe (2013, p. 330) supports Cowley's viewpoint advising teachers to consider what they want the pupils to achieve and carefully match the teaching strategy with the task.

Muijs and Reynolds (2014, p. 208) explain "direct instruction is based on an active role for the teacher, who must be expert in appropriately presenting the content of the lesson to pupils." Dakers (2011) further explains the approach to be linear because pupils are reliant on the teacher for direction, which could restrict their creativity and progression. The teacher's role during guided discovery tasks is remarkably different. Cowley (2005, p. 72) acknowledges the planning required for a guided discovery activity, the teacher has to consider their own learning, intellectualize it, then "set up a situation in which the children are likely to work in a creative manner," which may require a large number of resources. During the lesson the teacher will provide prompts for pupils who form misconceptions. Dymoke (2008, p. 49) discusses the importance that "the child is never left to struggle alone or, alternatively, given too much help which could stifle their developing independence" when employing a guided discovery strategy. The lesson set up allows pupils to take an active role in their learning, testing things out for themselves and evaluating the outcome, skills that constructivists argue are essential for deep learning. Tinkering tasks adopting a guided discovery teaching strategy could encourage a constructivist learning approach. However, the pupils' success could rely on how well the task has been set up by the teacher.

The 2011 Ofsted report into design and technology also raised several concerns about undemanding work at KS3. The lesson content at some schools was severely criticised, claiming it did not challenge pupils' thinking sufficiently. The report highlighted that pupils were often repeating learning from key stage 2 (KS2). These findings suggest failure to deliver the Department of Education (DfE) requirements for teaching standard 1, which specifies teachers should "set goals that stretch and challenge pupils of all backgrounds, abilities and dispositions" (DfE, 2013).

Robson (2015, p. 64) defines learning as a change in schema and explains how introducing a problem to a usual routine stimulates "cognitive conflict" forcing the pupil to reconsider a solution, often advancing their learning in a meaningful way as a result. This concept is echoed by Bruner (see Stockford 2013, p. 57) who developed Vygotsky's work on the Zone of Proximal Development (ZPD) to explain learning as a process whereby "the learner solves problems using their own knowledge and experience to develop new facts and relationships which, in turn, form new knowledge." Furthermore, Watkins' (2014) study into the principles of deep learning concluded that critical thinking led pupils to adopt "new approaches in relation to the material." Therefore, presenting pupils with problem solving tasks to challenge their thinking could better progress their learning, even encouraging them to use materials creatively. However, Watkins' (2014) research was based on the preferred learning styles of the "net-generation," implying that learning preference might also be a factor contributing to the success of a problem solving activity.

Considering these findings if teachers worked together to understand pupils' prior learning, perhaps tasks could be pitched so they are more challenging and build on pupils' prior

learning. Tinkering could improve the delivery of the KS3 programme of study, fostering deep learning, because it requires pupils to think iteratively in order to solve a problem.

In November 2015 the new National Curriculum guidelines for D&T GCSE were released. The content of this qualification outlines the need for pupils to engage in an iterative process for design and make tasks, aiming to channel their confidence in the technological world. New design and making specifications for GCSE must allow the opportunity for refining design decisions based on critical analysis and working collaboratively to “avoid design fixation” (DfE 2015, p. 7). Although iteration is also a requirement of the KS3 National Curriculum, Ofsted (2011) found some schools showed limited evidence for development of knowledge and skills through iteration.

Kolb (see Harrison 2008, p. 11) theorised that people learn from their experience and proposed an “experiential learning cycle” to explain the relationship between experience and learning. The learner reflects on their experience, then applies the learning in a similar situation at another time (experimentation). This creates another experience to reflect upon and the cycle continues. In addition to the work of Kolb, Robson (2015, p. 62) reasons that D&T teaching requires an essential combination of action and reflection to enable “learning through design.” This process allows pupils the opportunity to think, test and evaluate their ideas iteratively, fostering a deep learning experience, until they reach the best solution, something that is not always achieved in a linear design process.

Tinkering tasks lend themselves to the new outlines for D&T because they encourage problem solving through iterative thinking. Schools could better achieve the Ofsted requirement that pupils “physically explore the properties of materials and their working characteristics to understand the implications for designing and making” (Ofsted 2011, p. 48) by factoring time into the scheme of learning (SOL) for tinkering in order to help pupils refine their ideas to achieve a better functioning solution.

First teaching of the new D&T GCSE from September 2017 will require design briefs to be “open-ended” (DfE 2015, p. 5), so the materials used are not pre-selected by teachers and set in “real-world contexts” (DfE 2015, p. 5), aiming to build pupils’ understanding of the technological world. The 2011 Ofsted report warned that half of the secondary schools visited provided “insufficient opportunities for pupils to develop knowledge of electronics” (Ofsted 2011, p. 6). If the UK is to remain competitive in a global market it needs to keep up to date with technological advances and cannot risk schools running dated projects that have been done for generations.

Cowell (2015, p. 93) suggests “the use of kits can be an effective way of introducing pupils to some of the basic concepts involved in electronics.” However, some kits could limit creativity as the circuits are pre-planned by the manufacturer. To eliminate this problem Cowell (2015, p. 94) recommends using a kit that allows multiple outcomes. This open-ended approach could encourage pupils to tinker with new components and gain a deep learning.

Approaching electronics in combination with new materials could promote opportunities for pupils to advance their knowledge within the discipline. Introducing smart materials, such as e-textiles into the scheme of learning (SOL), allows the opportunity for inter-disciplinary tasks, whilst letting pupils consolidate their prior learning by applying it to a variety of contexts.

Given the time frame, this study will examine tinkering as a teaching strategy, considering the way it could shape lesson design and critically evaluating the implications it has on pupils' knowledge. The purpose of the study is to inform teaching practice to better progress pupils' learning of D&T in line with the Ofsted and National Curriculum guidelines at KS3. The study will focus on one class to measure their knowledge before and after a tinkering lesson to assess the impact of the teaching strategy.

Research Method

An action research method was chosen to test the theory of tinkering as a teaching strategy to improve pupils' knowledge. Cohen et al (2011, p. 344) suggest action research lends itself to studies that investigate teaching methods, for example "replacing a traditional method by a discovery method."

A year 7 class was selected for the study as their current rotation was textiles and their forthcoming rotation was electronics, an ideal opportunity to explore e-textiles components and blur the boundaries between D&T disciplines. The SOL was modified to incorporate an e-textiles tinkering lesson.

A series of tinkering challenges were trialled with 2 participants. This allowed for a detailed consideration of the learning process and informed the design of lesson, clue cards and timings for each task.

Teaching strategies suggested by Cowley (2005) replaced the direct instruction strategy during the tinkering activity. A framework for a tinkering lesson was devised to inform the role of the teacher, suggesting ten strategies for lesson delivery in line with current requirements. This involved prompting pupils if they became confused, offering a variety of resources to inspire pupils' creativity, structuring the lesson to ensure focus and safety and passing on background details that could be useful. Upon introduction to the task pupils were advised to take responsibility for the expensive equipment and examine it very carefully.

The pupils worked collaboratively, in pairs or groups of three, to explore the new equipment through a series of 'tinker-lab challenges.' Each group was given a 'tinkering kit,' which included a sewable LED, a cell, a piece of conductive fabric, a red crocodile clip and a black crocodile clip (good practice for positive and negative sides of the circuit). The first challenge was to make an LED light up using all the equipment in the kit. This was achieved by applying knowledge from KS2 to explore new technologies (sewable LEDs and conductive fabric) to create a series circuit. Pupils were allowed two minutes to explore the equipment independently before clue cards were made available.

The clue cards delivered facts about each piece of equipment including a picture, its technical name, use and the circuit symbol. Key aspects of the equipment such as the positive and negative sides were highlighted. Font size was 18 to promote an inclusive environment for pupils with visual impairments and dyslexia. The clue cards added an element of intrigue to the lesson and enabled pupils' learning to be scaffolded, whilst retaining their independence. The cards were laid out on a spare desk so pupils could help themselves on their own initiative if they required support.

The second challenge was to light up two LEDs using a parallel circuit. This was particularly challenging; parallel circuits had not yet been introduced to the class in KS3 science or D&T lessons. Each group was supplied with an additional LED and two more crocodile clips to

tinker with. A fifth clue card was available for pupils requiring support. Pupils explored the equipment and correctly pieced the information on each clue card together in order to complete the parallel circuit.

Sharp (2012, p. 46) explains that by using more than one method of enquiry researchers can cross-reference their findings, ensuring the validity of their study. In addition to the framework for a tinkering lesson pupils' acquisition of knowledge through tinkering was measured using pre and post-tests. Cohen et al (2011, p. 481) state, "one can only assess how much a set of educational experiences has added value to the student if one knows that student's starting point." It was necessary to test pupils before the activity to identify their starting abilities and then summatively after the activity to measure their progress.

A non-parametric test was designed, tailored to the learning outcomes of the tinkering lesson therefore allowing pupils the opportunity to demonstrate their learning. Questions were sequenced progressing from easy to more difficult and care was taken to test different orders of thinking in line with Bloom's taxonomy (see Dymoke 2008, p. 63). If a learning objective was easily reached the question in the test was also easily achieved and vice versa. Parts of the test that required recall gained fewer marks than those requiring justification to avoid artificially inflating pupils' results (Cohen et al 2011, p. 491). Clear verbal instructions, explaining how to answer the questions, were given to the whole class to support their completion of the test.

Working collaboratively with an experienced member of staff to examine the test for pitch, readability and ambiguity helped ensure valid data would be collected. Pupils' prior learning was checked with science and D&T departments, to ensure pupils would be exposed to new and relevant learning during the lesson in line with the English KS3 National Curriculum.

A number of control methods guaranteed the reliability of the research. Pre-tests and post-tests were taken at the same time of day (9am) to minimise a variation in pupils' capability. Pupils were allowed the same amount of time for each test (20 minutes) and the class teacher was present, consistent with other lessons. The lesson plan ensured that the teaching assistant (TA) was aware of their role and resources were ready. The post-test was taken directly after the intervention to "reduce the possibility of the influence of confounding effects" Cohen et al (2011, p. 327). To ensure this was done fairly all equipment and clue cards were collected in before the post-test was handed out. The post-test included the same questions as the pre-test, but was reformatted to avoid repetition. The questions were manually reordered. The test had a summated score system, the total score was calculated by adding up points gained for each question. Pupils' understanding was measured in a quantitative method, based on factual and numerical results.

Participants

The textiles class consisted of 21 pupils, 5 girls and 16 boys. The age range of the pupils was 11 years 9 months to 12 years 7 months. The average reading age for the class based in the data available was 8 years 2 months. The target grades for D&T ranged from 3a to 5b. There were 11 pupils with special educational need (SEN) in the class. These needs included behaviour, visual impairment, ADHD, dyslexia, dyspraxia, autism, auditory, severe learning difficulty and moderate learning difficulty. Copies of the test and resources were provided in yellow for pupils where necessary to minimise any barriers to learning. A teaching assistant (TA) was present each lesson to offer 1:1 support with reading and writing to one pupil. Due to the low ability of the class the research will be limited as results will not account for mid

or high ability learners of the same age range. Due to pupil absence a full set of data was collected from 17 pupils.

Data

To calculate the results the pupils' answers for the pre-tests and post-tests were scored against the mark scheme and a total mark was given out of a possible 19. The results before and after tinkering were then analysed.

	Pupil (names replaced with letters for safeguarding and ethical reasons)																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Test result pre- tinkering	5	4	7	3	6	4	10	5	6	4	17	13	11	6	10	6	13
Test result post tinkering	3	14	9	13	7	19	12	13	7	6	16	18	14	10	16	14	15

Table 1.0 shows the test results as raw data.

Note: All marks are out of 19

Table 1.0 displays the results of each pupil's test before and after tinkering. 15 out of 17 pupils increased their result after tinkering.

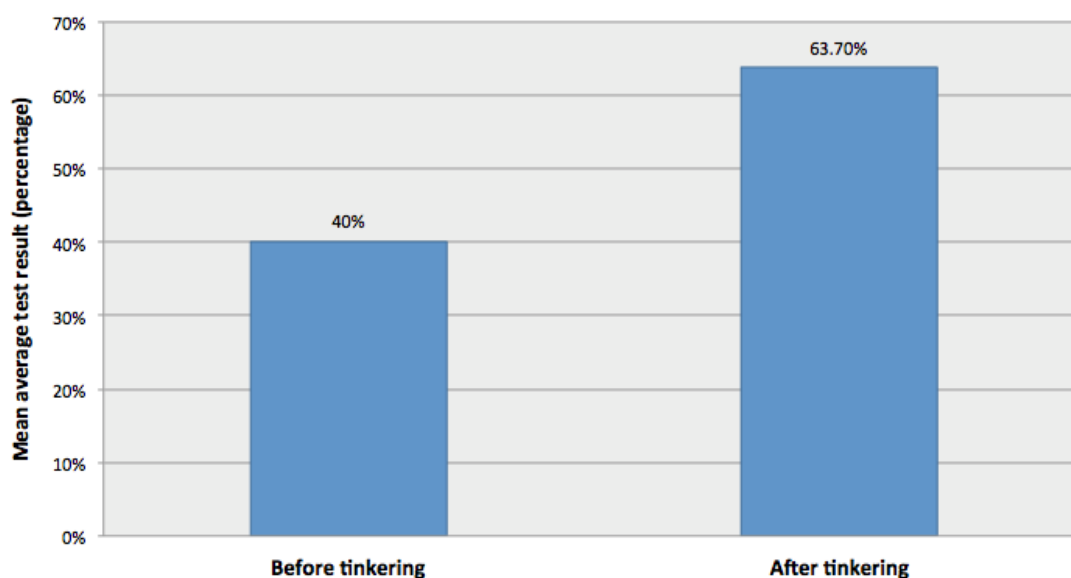
Mean test result before tinkering	Mean test result after tinkering
7.6	12.1

Table 1.1 shows the mean average test results before and after tinkering.

Note: All marks are out of 19

Table 1.1 highlights the mean average test result increase for the class after tinkering is 4.5 marks.

A graph to show the comparison between the mean average test result before and after tinkering



The mean average increase calculates to a 23.7% improvement in results after tinkering, this finding is displayed in the above bar graph.

Analysis of findings

Upon cross-referencing the framework for a tinkering lesson and field notes made directly after the lesson it was clear pupils had worked collaboratively to solve the problems by exploring e-textiles components, without being led by direct instruction from the teacher. Some groups worked for longer without clues than others and some groups did not use all the clues to solve the challenge. It was observed that the freedom to tinker with new materials allowed pupils to be actively engaged with their work and develop their independence. The work encouraged an iterative thought process as pupils tested and refined their ideas in order to complete the challenge, working at their own pace. Pupils were excited by the task and displayed a fail-forward mind-set, working with determination to make the LED light up.

Pupils' motivation was apparent; they were keen to show off their achievements 'Miss, we've done it, look!' Despite not taking a product home the class worked excitedly to complete the challenges, 'Can we do more?' This observation enhances my understanding of Barlex's (2015) model for D&T tasks, supporting the concept that not every D&T experience needs to result in a finished product for pupils to be engaged.

The lesson benefited from routines and expectations already established in previous lessons through direct instruction, such as the distributing of equipment and seating arrangements. If the pupils were experiencing a new teacher they might struggle with the structure of a tinkering lesson as certain boundaries such as noise level would not have been established, which could result in more challenging behaviour. Further study into the relationship between tinkering and behaviour management would help us to reach a conclusion on this matter.

The findings of the study show that tinkering can improve pupils' knowledge, allowing them to work iteratively and solve problems using their higher order thinking skills. One isolated value (pupil F) showed a significant achievement. The tinkering challenge advanced their knowledge by 79%. Although pupils' achievement increased in the post-test, their knowledge retention would require further study to examine if they had experienced a deep learning, for example re-testing their knowledge a week after the lesson, then 2 weeks after the lesson and so on.

There are two rogue values (pupil A and pupil K), whose results did not increase after the tinkering activity. Pupil K worked with the TA who may have provided less support during the post-test as the content was more familiar. Pupil A was issued a sanction during the lesson, which may have had a negative impact on their efforts during the test. Alternatively, the lack of direct instruction may have meant these pupils formed a misconception whilst tinkering, which was not successfully addressed in the lesson, a concern of Lowe (2013). To address these deficiencies teachers could allow time following the tinkering challenges to consolidate learning and address misconceptions, for example inviting pupils to draw their circuit diagram on the whiteboard as part of a class discussion. A future study could assess if making time in the SOL for inter-discipline tasks between rotations could further support consolidation of knowledge and advance pupils' schemas, building connections between the different D&T disciplines.

Working with teachers to understand the curriculum content in science and D&T electronics ensured that tasks were pitched correctly to build on pupils' prior learning, challenging their thinking to move them across their ZPD and advance their schema. Assessing pupils' baseline understanding using a pre-test supported this good practice and helped identify key learning opportunities when designing the tinkering resources.

The resources were designed following the pilot study to provide relevant background facts for the task. The teacher worked consistently within the framework for a tinkering lesson to provide prompts for pupils. These teaching strategies ensured that no pupil was left to struggle alone, so the risk of demotivation from failure was minimised. They also encouraged the pupils' independence, as they were less reliant on the teacher for information.

The pupils worked sensibly with the expensive equipment throughout the lesson. No components were lost, therefore the one-off investment for equipment will benefit other classes too. The flexible nature of the kits means tasks can be adapted to best suit the needs of a range of key stages within the secondary school.

Providing time for tinkering allows pupils the opportunity to test new materials, form evaluations and adapt their solutions to achieve the best outcome in an iterative process. Through their tinkering pupils found they could create solutions that the teacher had not thought of. Two groups managed to light up both LEDs by creating a circuit with a different layout to that on clue 5, this supports the use of kits that offer multiple outcomes to enhance creative thinking (Cowell 2015). Providing a wider selection of e-textiles components and posing the challenge 'Can you get the LED to light up?' may have been a better approach to avoid pre-selection of the resources and better meet the English National Curriculum directives. However, given the pupils' prior knowledge and ability this approach may have been an inappropriate pitch for the class studied within the timeframe.

Conclusion

The study set out to determine if tinkering could benefit pupils' learning in D&T lessons at KS3. The findings suggest that by allowing pupils the freedom to tinker with e-textiles components they can work iteratively to improve their knowledge and find solutions to problems of high demand. Active involvement in lessons through the use of practical tasks helps pupils form a deep learning. Teachers must ensure adequate support is available when employing this teaching strategy, so no child is left to struggle and risk becoming demotivated. Developing creative iterative skills at KS3 will help prepare pupils to meet the requirements of the English National Curriculum subject content for GCSE at KS4.

When planning future schemes of learning teachers should endeavour to include a range of teaching strategies, matching the learning outcome to an appropriate teaching strategy. Teachers should not overly rely on one teaching strategy, but flex between a variety to avoid stagnation and allow every pupil the opportunity to succeed during lessons. This concept also supports constructivist theory that pupils need to apply the learnt knowledge to many different experiences in order to form a deep learning. Failure to allow time for consolidation of facts after tinkering could result in misconceptions forming in pupils' schemas and some could become confused leading to underachievement.

Another consideration when planning a scheme of learning is pitch. The study shows that by liaising with different subject areas and D&T disciplines, teachers can ensure lessons are

pitched correctly to challenge pupils' thinking, avoid repetition of tasks and build on prior learning to better meet the government guidelines.

The use of kits has been shown to have a number of benefits, particularly when learning about technological advances in the real world; firstly the components can be reused with a number of classes, which may help reduce spending in the department. This factor can also be addressed by encouraging group work, for example sharing one kit between a number of pupils. Secondly, kits with multiple outcomes avoid all design decisions being made by the teacher and have proved successful when encouraging creative thinking, iteration and gaining knowledge.

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