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Science and Mathematics through a Technological Design Context: The Potential

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CONTEXT

As technology and engineering education has evolved in recent years, little emphasis has been explicitly placed in its potential to blend in STEM (Science, Technology, Engineering and Mathematics) subjects naturally with an emphasis on practicable knowledge which develops an understanding well consistent with the scientific theories. With this paper we wish to contribute to the knowledge on how practical hands-on activities and experiments in technology (school curriculum) can use basic maths and specific principles and theories from science.

PURPOSE OR GOAL

One of the goals of STEM education is to help ensure the knowledge, conceptual understandings, and critical thinking skills that come from studying STEM subjects are gained by students. This can be achieved through a learning environment in which learning strategies and approaches are personalized and adapted to the learner's own learning styles and by creating a learning environment which promotes effective learning. To achieve such a learning environment, it is crucial to understand the current practices of teaching in schools and to adopt methods which provide rich learning experiences for students through their active engagement in the learning process.

APPROACH OR METHODOLOGY/METHODS

This research proposed to study the classroom practices of a technology teacher and 19 of his students (age 15-16; Year 11) in a technology classroom. The collection and processing of data was made through observation field notes, audio recordings taken during classroom observations, interviews, discussions, photographs of students working and student technology portfolios.

ACTUAL OR ANTICIPATED OUTCOMES

A variety of perspectives were noted by the students in the observations and conclusions they made in their portfolios, which are consistent with scientific explanations. Giving the students an opportunity to investigate, it can be argued that connections between technology and other disciplines can be made explicit in a technology classroom.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

We can appreciate the position of technology in the curriculum and its potential to illustrate understanding through the practicality of real-life authentic scenarios using concepts in science. An enriched authentic context in technology naturally enhances knowledge transfer. The technological knowledge acquired by the students in doing technology in authentic situations can provide a stepping stone to help the students to apply the knowledge in the 'real world'.

Keywords: Technology. STEM (science, technology, engineering, and mathematics). Integration. Interaction. Technological Design Context

Introduction

The transition into the 21st century has led to a greater emphasis on the development of student proficiencies in Science, Technology, Engineering, and Mathematics (STEM), with a particular focus on how these skills will help students thrive in the technological society. One of the goals of STEM education is to help ensure the knowledge, conceptual understandings, and critical thinking skills that come from studying STEM subjects are gained by students (Hacioglu & Gulhan, 2021; Walton & Johnson, 2015; Modi, 2011; PCAST, 2010). STEM education offers significant opportunities for improving student motivation and engagement due its hands-on nature of the individual discipline area. There are concerns that students disengage with disciplines of mathematics and science which may hinder the intent of STEM initiatives, and these must be addressed. This can be achieved through a learning environment in which learning strategies and approaches are personalized and adapted to the learner's own learning styles.

A brief review of the literature about 21st century skills suggests that the past teaching methodologies are not sufficient for today as the education and skills of the workforce are the single most critical element for successful innovation (Johnson, 2018; NCREL, 2003). There has been evidence gathered from various science-based design programs (K-12) which suggests that children tend to generate low-level factual questions rather than questions that could extend their understanding in problem solving (Scardamalia & Bereiter, 1992). Many students lose interest in science and mathematics at an early age, and thus make an early exit from the so-called "STEM pipeline" which is one factor in a workforce having low science and/or mathematics ability. Students often find it difficult to apply and integrate knowledge they have acquired in a classroom to real world problems. Traditional subject disciplines, according to Beane (1991, 1995), are "territorial spaces carved out by academic scholars for their own purposes" (p. 9), and their boundaries limit student access to broader meanings. These findings support the need for an integrated learning environment to develop interdisciplinary thinkers (Hoeg & Bencze, 2017; Smith & White, 2019) who can consciously apply methodology and language from more than one discipline to make connections in content that cuts across subjects. Effective integrated measures need to be taken which will provide students with the knowledge, skills, tools, and resources to educate and motivate them to engage with STEM and to strengthen their ability to participate in society and the economy.

STEM as integrated learning

Students often find it difficult to apply and integrate knowledge they have acquired from the classroom to real world problems. This may be attributed to teachers practice of moving from topic to topic without any logical connections among them (Wineburg and Grossman, 2000). Beane (1995) argues that classroom instruction should be constructed in a way to support the core subject area with a potential to bring in cross-disciplinary knowledge and skills which encourages students to participate effectively. Beane advocated that addressing real-life questions of interest to students through an integrated curriculum will help promote wholeness and unity rather than separation and fragmentation (Jacobs, 1989) so learning becomes focused, connected, and relevant to learners (Vatterott, 2007; Park et al., 2018). Isolated science or maths concepts can be more sensible if the real-life application is discussed and demonstrated to students.

Within a STEM approach, there is significant potential for technology education in schools to be the vehicle for the integration of cross-disciplinary learning. STEM promotion often emphasizes improving student achievements in mathematics and science, and many technology educators promote goals such as increasing student motivation, competence and demonstrating the usefulness of mathematics and science (Johns & Mentzer, 2016; Guzey et al., 2020). An understanding of the practices of students and teachers in a technology classroom is necessary to develop strategies surrounding the design and delivery of an 'integrated' instruction for STEM in secondary education.

Research, Methodology and Educational Context

This research studied the classroom practices of a technology teacher and 19 of his students (age 15-16; Year 11) in a technology classroom which had a focus on the knowledge and skills students used through investigation and experimentation while designing individual projects (street luge: a gravity powered vehicle). One of the constructed street luges has been shown in Figure 1 for reference.

Figure 1. A snapshot of a street luge manufactured by a student.

The research study provided an insight into students' perceptions about integration and the knowledge (science, mathematics and technology) they bring to a technology classroom during early design stages. The four school terms (approx 10 weeks each from February till December) of the school year provided the time periods for the aspects of the project: design in Term 1, construction in Term 2 and Term 3 and testing and evaluation in Term 4. This paper will present data from the initial stages of the project (Term 1 design stages) where investigation and experimentation were carried out in the classroom to develop an understanding of the specifications and attributes which need to be fulfilled as a part of the construction of the luge. The collection and processing of data was made through observation field notes, audio recordings taken during classroom observations, interviews, discussions, photographs of students working and student technology portfolios. A daily account of every classroom period was maintained throughout the year by the researcher as summary of field notes and self-reflective remarks during and after data collection.

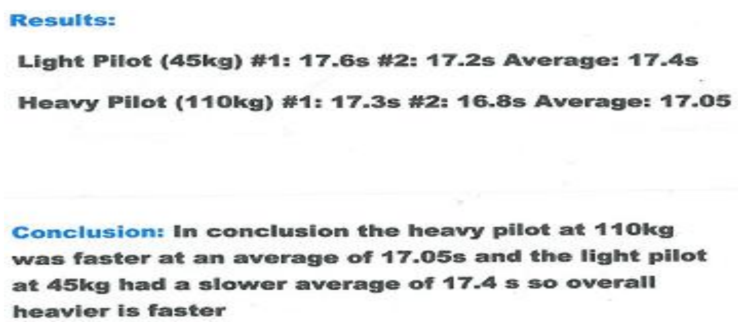
The collected data was used to answer the research question: *How students worked in a technology classroom to integrate science, mathematics and technology while performing experiments?*

Findings

Evidence from the initial questionnaires suggested that students choose to take technology in Year 11 as they found, from their previous experiences, the practical aspect of technology to be fun, beneficial, and meaningful for their professional and vocational goals. These students also took science and maths as separate subjects in school. In the initial student questionnaire, most of the students anticipated that they may need knowledge from other subjects, especially science (aerodynamics, forces), mathematics (measurement and counting), arts (design) and English (communication) to complete the luge design project as part of their technology curriculum.

This paper will focus on an initial aspect of the project during Term 1 called 'the momentum testing' phase, where experiments were performed with the appropriate 'controls' looking to study the relationship among variables such as wheel sizes (50 mm, 70 mm and 100 mm diameter) and pilots weight (45 kg and 110 kg) to determine the best combination to provide the optimal speed for the luge over a set trial distance (a track at the school backyard). Two sets of readings were taken for each pilot, using the same wheel size (70 mm diameter) and the time taken to cover a specific down-hill distance by the two drivers were recorded.

This data was discussed by the students in the design room at the next technology session, which provided the opportunity to think and reflect about their field data. Experimentation was carried out which included data collection, calculation of average time, analysis and drawing conclusions based upon the available statistics as shown in Figure 2:


Results:

Light Pilot (45kg) #1: 17.6s #2: 17.2s Average: 17.4s

Heavy Pilot (110kg) #1: 17.3s #2: 16.8s Average: 17.05

Conclusion: In conclusion the heavy pilot at 110kg was faster at an average of 17.05s and the light pilot at 45kg had a slower average of 17.4 s so overall heavier is faster

Figure 2. A conclusion drawn by a student in their technology portfolio

The teacher-initiated discussions focused around achieving an understanding of the collected set of data by the students. The students were provided clear understanding on the variables which were 'controlled' as a part of the experiment during the discussions, which were the standard wheel sizes and the pilot weights. The classroom discussion has the potential of embedding scientific investigative skills through experimentation in a technology classroom. The teacher asked the students to think about the collected data along with technological concepts to justify their observation. However, the teacher did not consider it significant at this point to initiate discussions where science principles could have been used to justify the technological outcome. The conclusions derived by different students in their portfolios (see Figure 2 & 3) highlight experimentation performed to formulate conclusions based on some basic mathematical calculations. The student systematically presented their observation from the collected data for both the 45 kg and 115 kg pilots and derives conclusion based on the two trail tests performed in the field. As observed, students communicated their findings based on their practical experience which included an understanding of the observed phenomenon as perceived by them through observations and experimentation. It is interesting to observe that the teacher and students did not consider it significant at this stage to explain their observation using principles and concepts from science like force, friction, or energy principles. The conclusion was based purely on the collected data from the field.
It is interesting to observe that a few students from this class did conclude that the difference between the observed readings were not significant enough to conclude that the heavier pilot is faster.

A scientific explanation of their conclusion is as follows, it is our basic understanding that any object (round object) placed on a tilted surface (inclined plane) will often roll down at a rate which depends on the tilt or the inclination of the surface to the ground, so greater the tilt, the faster the rate at which the body will roll down.

Scientifically, no other force except gravity accelerates the body (street luge) down the inclined plane and in the absence of friction and other external forces; the linear acceleration of the body (street luge) down an incline (down-hill) is independent of its mass (pilots mass) which can be proved using basic energy conservation principles and Newton's laws. If the frictional resistance is considered (which will be the case in real life), acceleration can be shown dependent on gravity and independent of the mass of the rolling object. The objects should 'hit the ground level at the same time. A few students did mention that the heavier pilot took less time which contradicts Newton's laws, but an explanation of such a conclusion derived by the student can be explained.

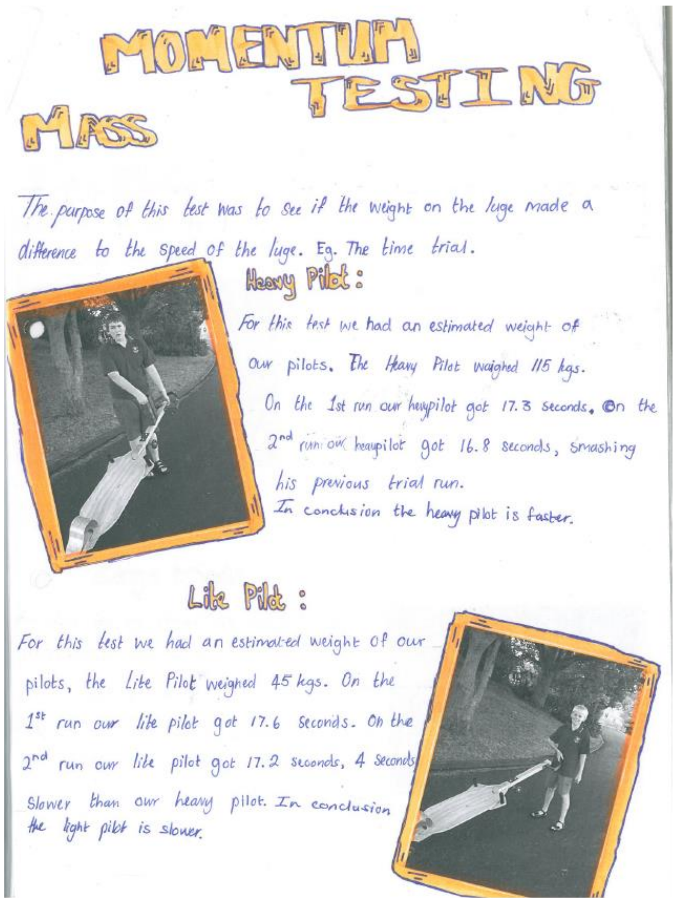


Figure 2. A page from a student portfolio

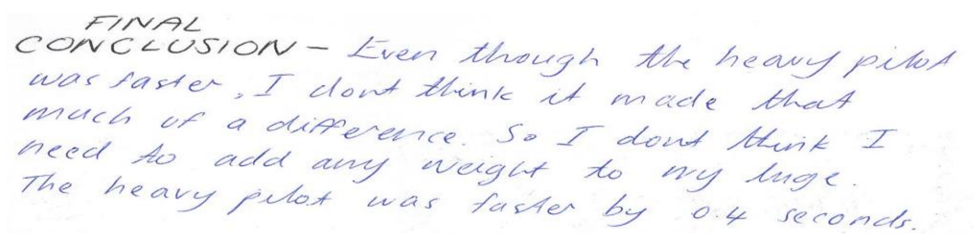


Figure 3. Conclusion derived by a student in their portfolios.

The student developed an understanding from the results of this experiment that a heavier person has a slight advantage over a lighter person in terms of speed. The test pilots (heavy and light) started setting off their luge with a self-initiated velocity to set their luge in motion. The reason for the contradicting data can be explained on the basis of the greater kick-off velocity generated by the heavier pilot than the light pilot. Students might not have understood the concepts/reason behind the difference or might have not considered it important at this stage to explain their findings considering abstract concept of forces, momentum, principles of conservation of energy or centre of gravity, but an analysis of some student portfolios reflects that a general understanding that 'mass does not largely affect the speed' was developed by the students from their practical experience and recorded values (see Figure 3 and 4). The students observed that the heavier pilot took less time in covering the same distance as compared to a lighter pilot, and a few students also mentioned in their portfolios that this difference was insignificant (Figure 4); indirectly implying that mass has no effect on the speed justifying the concept from science. However, it is not obvious at this stage that if the students considered factors like frictional resistance and other errors (mechanical and human) while deriving their conclusions which may have accounted for the slight variation in their observed values, but no such considerations were found in the portfolios. The most striking results to emerge from the data set is that most of the students derived appropriate conclusions based upon their experience and observations in the technology classroom, which aligns with the concepts from science. The theme of heavy pilot was faster has reoccurred through the data set but some students have also mentioned that such a difference is insignificant.

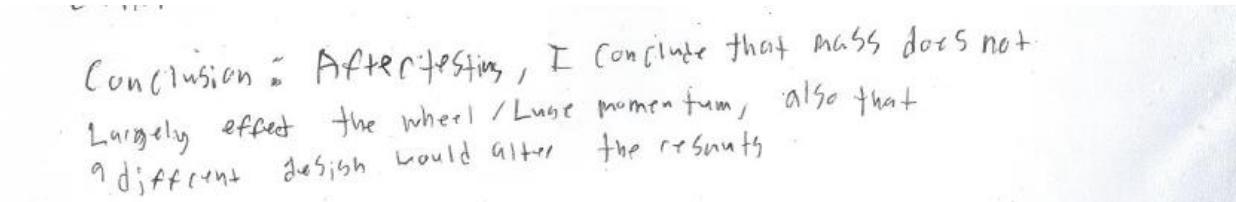


Figure 4. The conclusions derived by three students in their technology

One student also indicated that a heavier pilot is more ‘sticking to the ground’ implying a better ‘centre of mass’ distribution which provides a safe riding and less toppling (instability) than a lighter pilot (see Figure 5). It can be concluded that this student was developing an understanding of the ‘centre of gravity’ concept while investigating the evidence gathered, which seems to be consistent with the principles of science.

This natural integration of science and mathematics in technology indicates students developing a practical understanding from the observed phenomenon which can be supported by scientific principles. It is worth noting that the procedural aspect of technology provides a stage for recalling and warranting established science ideas and content. Technology could be used as a platform to recall concepts from science to explain the experimental observed phenomenon or the structural mechanism to provide between theory and practice.

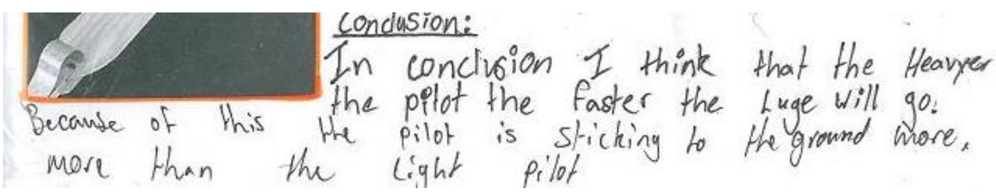


Figure 5. Conclusion derived using the ‘centre of gravity’ principle.

The Level 1 achievement standards document number AS90940 published by the New Zealand Qualification Authority (NZQA) for Science (Year 11) establishes the various criteria for achieving the Standard by demonstrating understanding of aspects of mechanics. The document suggests that students should show awareness of simple facts, phenomenon, concepts and principles related to various situations. The standard also requires students to show comprehensive understanding of aspects of mechanics, providing evidence that justifies, why certain phenomenon, concepts and principles are connected in a context. The aspects of mechanics include distance, speed, acceleration, deceleration, mass, weight, balanced and unbalanced forces, basic Newton’s laws, pressure and energy principles.

This research indicates the potential of technology in the school curriculum to serve as a vehicle which could be used to illustrate concepts from science to assist students to explain their field observations. It could be a challenge for the technology teacher to integrate science and mathematics in a technology classroom since it involves careful accumulation of information from science and mathematics. However, this episode clearly highlights the role a technological design context can play to establish an integrative learning environment which could be achieved through collaboration with science and maths teachers.

Discussion and Conclusions

Technology as a school subject can play a significant role not only to develop technological literacy people but also to develop students' understanding of scientific explanations by making the relevance of science and maths subjects more explicit. Technology education programs focus on practical hands-on activities and these activities have potential to create an integrative learning environment, as shown in this project.

A variety of perspectives were noted by the students in the observations and conclusions they made in their portfolios, which are consistent with scientific explanations. It can be argued that connections between technology and other disciplines can be made explicit in a technology classroom. Students can be encouraged to analyse their findings using appropriate cross-disciplinary content, which is influenced by the context, but such an approach should be carefully considered and carried out as the purpose of doing technology should not be restricted to learning concepts from other domains. Technology should drive the contents from other subjects to make the observed phenomenon sensible in terms of the contextualised technological knowledge. Students may appreciate the interrelationship of science and mathematics in a technological context and the relevance of the information in other disciplines which could lead to the transfer of knowledge in technology. Technology education should be a key partner in experiential education through the integration of science, mathematics, and technology because such an approach will help bridge the gap between classroom teaching and authentic learning contexts (Duran & Şendağ, 2012; Furner & Kumar, 2007; Berlin & White, 1992). Students can be provided a chance to appreciate how variables in practical setting can influence design decisions.

The working of many product components and their assembly can be explained by concepts from science. The teacher in this study did not rely on concepts from science to assist students to justify their data collected from the field, as it may not have been necessary to introduce concepts. The momentum testing phase conducted to study the effect of different pilot weights on the speed of the luge is an example of investigating variables using the available technology and deriving technological knowledge to make appropriate design decisions. A detailed analysis of the student claims in their portfolios indicates that most students concluded that the heavier pilot is faster than the lighter pilot, without a scientific reasoning behind their claim, but the investigative outcome was considered technologically appropriate by the teacher and students at this stage.

Students may not have expressed their understanding by using science principles and terminologies while writing their conclusions, but they came to a meaningful consensus about the experiment and reported their findings in an intelligible way. Such experiments should not be seen as "trial-and-error" or "hit-and-miss" processes; but rather as the student's interpretation of results to interpret both expected and unexpected outcomes in technology.

This paper proposes that developing technological design contexts which are real, purposeful, and useful is an important factor in engaging students, which naturally entails the use of science concepts and mathematical operations with or without student's knowledge. If we assume the models proposed by numerous authors are correct in that student perceptions are central to their participation and learning of subjects (Ethington, 1992; Khoon & Ainley, 2005; Markku, 2002; Murphy & Gibbs, 1996; Thomson & Fleming, 2004; Wigfield & Eccles, 2000; Hacıoğlu, 2017), the findings from this study are encouraging for technology educators where science and mathematics finds its natural fit and application.

Recommendations

In technology classrooms, careful steps can be taken to relate what students already know to connect with context. The technological knowledge acquired by the students in doing technology in authentic situations can provide a steppingstone to help the students to apply the knowledge in the ‘real world’. The following suggestions are made for technology teachers, STEM educators, School outreach team and researchers:

1. To develop critical thinking within a technological design context, students must be allowed to participate in authentic design and construction activities, and their own opinions and as well as their peers’ opinions at each stage of the process with an inquisitive perspective.

2. There is an opportunity to increase the workforce in the STEM, which is the ultimate goal of STEM education. Through technology curriculum in schools, students’ perceptions of STEM fields could be enhanced. Thus, the implicit or explicit messages given during the STEM applications or by the teachers are of vital importance in schools.

3. Students develop understandings in technology sessions based on their participation and practical observations. Educators must carefully introduce intra disciplinary concepts which could lead to improved productivity, process and finally the end product/service.

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