

Building Bridges Across the Disciplines: Learning Science Through Technology

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Abstract

The purpose of this study was to investigate students' learning and understanding of the concept of forces in the context of a Year 9 class studying an integrated technology unit called the Bridge Project. Data consisted of cases prepared from observational field notes and formal interviews with the teachers and five of the students in the class. The results of the case study indicated that all five interviewed students recognised passive forces involved in the equilibrium situation of the bridge and four of the five students appeared to accept a force as a feature of interaction between two objects. The results were surprising when compared with a vast body of literature that suggests that the majority of students of this age associate forces only with movement and as a property of a single object. Several aspects of the course that may have contributed to the students' understanding of forces are discussed.

Recently in Western Australia, subjects such as manual arts, home economics and computing have been superseded by the new learning area of Technology and Enterprise. This new learning area, to be implemented in schools over the next four years, is described in the recently published *Curriculum Framework* (Curriculum Council, 1998) and has a status equivalent with more traditional learning areas such as science, mathematics and English. The Technology and Enterprise learning area is directly linked with the Science learning area in the Curriculum Framework and curriculum integration is encouraged throughout the document.

Calls for the introduction of technology into the curriculum have not been isolated to Western Australia. In the United Kingdom, Price and Cross (1995) suggest that this change has been fuelled by economic difficulties and high unemployment and that the aim of these developments has been to make science better understood. This may well be the case in Australia and other countries, but the question remains, what does curriculum integration look like in practice? What do students learn about science when taught in an integrated context? Evaluations of the effects of curriculum integration on practice are not common in the literature (Hargreaves, Earl and Ryan, 1996). In an effort to contribute to this literature, this study investigated students' learning and understanding of forces in the context of a Year 9 integrated technology unit called the Bridge Project.

Integration

Curriculum integration is highly promoted as a cure for many of the ills associated with the teaching of middle school aged students such as the alienation they feel from the curriculum and the more traditional school structures (Bean, 1991). Others argue that a common problem with curriculum integration is that its meaning is "often vague, unclear, ambiguous or even vacuous" (Hargreaves, *et al*, 1996, p.99). What exactly is curriculum integration and how far should it go in abolishing the traditional disciplines? Claims have been made that "virtually no empirical support exists for the superiority or desirability of organising curriculum/instruction into either a thematic or integrated approach" (Lederman and Niess, 1997, p.58). An *interdisciplinary* approach, where the integrity of the academic disciplines remains clear and the connections between the subjects are emphasised, is supported by Lederman and Niess (1997). They suggest that with an interdisciplinary approach teachers are flexible to explicitly address critical mathematics and science concepts.

Learning about Forces

While there were many aspects of science and mathematics incorporated into the bridge project, this investigation focused on the students' learning of concepts related to forces. A recent summary of research about students' learning and understanding of forces (Driver, Squires, Rushworth and Wood-Robinson, 1994) reported that high school students tend to associate forces only with movement, not recognising the passive forces involved in equilibrium situations. For example, a Norwegian study (Sjoberg and Lie, 1981) reported that more than 50% of a sample of 1000 upper high school students did not recognise passive forces. Erickson and Hobbs (1978) found only 9 of 28, (32%) 12-14-year-old students recognised forces acting in both directions when a weight is pulling on a fixed string and Minstrell (1982) found that only twelve of a group of 27 high school students (44%) thought that a table exerts an upward force on a book resting on the table. Driver *et al* suggested that these results are a consequence of learners thinking of forces as a property of a single object rather than as a feature of interaction between two objects.

A series of bridging analogies were found by Clement (1987) to be useful in tutoring students and remediating their misconception that a table does not exert an upward force on a book resting on the table. By discussing a book resting on a spring and a book resting on a flexible table and then returning to the problem of the book on a normal table, the researchers found that students were more likely to accept the idea that the table exerts an upward force

on the book. A load on a bridge is similar to a book on a table in terms of the equal and opposite forces in action. For this reason, Clement's (1987) bridging analogies were utilised during interviews with students in this study (see the method for more details).

This study brought together two important avenues of research, firstly an investigation of student learning in an interdisciplinary setting, and secondly, an investigation of students' understanding of forces. By doing this, we hoped to explore whether the contextualised nature of the bridge project was beneficial for students in terms of learning science concepts.

The Bridge Project

The design and technology teacher in this suburban, high school, Ms O'Reilly (pseudonyms are used throughout the study), developed an engineering science course incorporating science and mathematics principles and practices within technology projects. The technology studies course is a Year 9 (13/14-years-old) optional unit comprising two, one-hour lessons per week. The course attracts a wide range of students of different ability levels. Ms O'Reilly said that regardless of their ability levels, most of the students are "interested and motivated". The class involved in this study comprised 15 male students. The students were involved in several projects throughout the year, one of which was the bridge project.

The bridge project was a five-week course requiring groups of two or three students to role play a bridge construction company. The students were informed that another company had gone bankrupt, leaving one of their bridges unfinished and they were to use the information they discovered about structures to complete the job. Students were asked to produce a strong, aesthetically pleasing bridge, while minimising the cost. Design criteria included a span of 750mm with no support or legs and support capacity of two cartons of coke cans. The bridge was to have a maximum of 25mm vertical deflection under full load, constructed from the materials on the official supply list with tools available in the workshop and cost under \$150.00 in 'bridge bucks' (play money supplied by the teacher).

In the first two weeks of the course, the students completed several investigations about structures, beams and bending, joints and jointing, and were introduced to types of forces, the history of bridges and bridge types, before planning their bridges. The students designed, manufactured and evaluated their own bridge before the class evaluation where prizes were awarded to the structure with the best strength to weight ratio, the most aesthetically pleasing bridge and the cheapest bridge that met all the design criteria. A prize also was awarded to the group who submitted the best written documentation of their project.

Method

Seven of the 10 lessons in the five-week course were observed. The first author of the paper used field notes to record the activity of the teacher, the students and students' responses to the teacher's questions about their bridges. Interviews with five students were conducted one week after the completion of the course. Students were selected in collaboration with the teacher, with the aim of interviewing a range of academic ability students from as many groups as practical. The semi-formal interviews consisted of a list of prescribed questions, however, the interviewer adjusted the scope of the interview according to individual student's responses. The first seven questions elicited the student's description of his bridge, his reasons for the design, opinions about what was learned during the project and the usefulness of science and mathematics knowledge for the construction of the bridge. The final three questions were specifically aimed at probing the students' understanding of the forces acting when a load is placed on a bridge. These questions were adapted from Clement's (1987) investigations of students' understanding of forces. Students were asked about the forces acting in three diagrams (Figure 1). Diagram A was of a load on a straight bridge, diagram B was of a load on a bridge that was flexed in a downward direction and diagram C was of a load on a spring.

The teacher was interviewed two weeks after the completion of the course with the aim of documenting her general reflections and opinions about integrating science, mathematics and technology through the bridge project. All interviews were audio-taped and

Figure 1: The diagrams used during interviews with students (adapted from Clement, 1987)

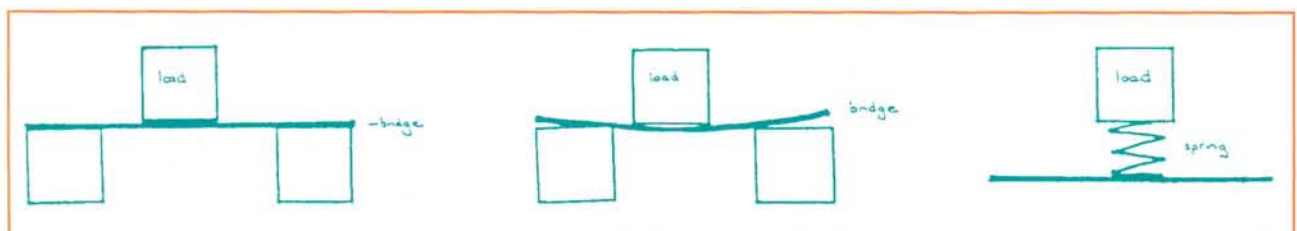


Table 1: Student responses to diagrams A, B, and C during the interview.

Student	Response to Diagram A	Response to Diagram B	Response to Diagram C
Gavin	↓ ↑	*	*
James	↓ ?	↓ ?	↓ ↑
Adam	↓ ↑	↓ ↑	↓ ↑
Steven	↓ ↑	↓ ↑	↓ s
Lawrence	↓ *	↓ *	↓ X

Key for Table 1:

↓	– student said there is a force acting down on the load
≠	– student said there is a force acting up on the load
*	– question not asked in interview
s	– student said there is a small force acting up on the load
?	– student said they don't know whether there are any forces acting in that direction
X	– student said there is no force acting in that direction

transcribed. The students' ideas about the forces acting in diagrams A, B and C were summarised and tabulated (Table 1). The student and teacher interview transcripts and field notes were reviewed by the researchers so that a case story about each of the students' experiences during this course could be constructed. The five case stories, field notes and interview data were used to generate discussion about the aspects of the course that may have contributed to the students' understanding about forces.

Results

The results of the interview are summarised in Table 1 which shows the five students' ideas about the forces acting in diagrams A, B and C. This table is referred to in three case stories about Gavin, Adam, and Lawrence presented below.

Gavin

Gavin was described by Ms O'Reilly as creative and prepared to take a risk. She said that Gavin asks a lot of questions in class and will (light heartedly) challenge her if he thinks she has made a mistake. Gavin worked with Colby to make the bridge for this project and, like most of the other groups, they constructed a deck bridge from two pieces of plywood with "I" beams in-between. Gavin said they tested different beam structures with pop sticks at the beginning of the project and found that triangles and "I" beams were strong but the triangles were too expensive.

Gavin and Colby spent considerable time during one lesson debating whether to spend more money strengthening their bridge or to make it more aesthetically pleasing. They also said they were wondering whether to do this at all, because the bridge was already strong and

they could get a prize for spending less money. They decided to add suspension "because it will add some strength and it doesn't cost very much." Gavin had to work out the cost of the string. He wanted 3000mm of string and he knew that the string cost \$1.00 for every 300mm. He had difficulty doing the proportional problem to work out how much he had to pay. Ms O'Reilly helped him work out that the string would cost \$10.00 by doing the cross multiplication on the blackboard. When he saw the calculation he said they do those all the time in mathematics.

Gavin and Colby decorated their bridge with dowel rods and string, spray painted it and covered the ends so that the internal "I" beams were not visible. The students then covered the bottom of their bridge with corrugated cardboard "to make it look good." During testing, when two cartons of drink cans were placed on top of Gavin and Colby's bridge, it deflected slightly, but not more than the 25mm limit. This group won the "best looking bridge" competition and the teacher from the English department who did the judging said that the suspension presented pleasing curves, the bridge had slim, clean lines and the corrugated cardboard was interesting.

Gavin said that their biggest problem during construction was working out how to fix the top deck on their bridge. The glue from the hot glue gun dried too quickly, so they decided to use PVA glue even though this meant the bridge had to be clamped and left to set. They also had difficulty reinforcing some screws and they solved that problem by drilling them into the "I" beams. The students only spent one hundred of the one hundred and fifty bridge bucks they were allocated and Gavin said they could have spent less, but they decided to

spend some on decoration. Gavin felt that learning about the “I” beams and triangles being strong structures was important and that his mathematics knowledge was useful for measuring. He also said that his scientific knowledge was useful for finding out a lot about using the “I” beams and the triangles.

When asked during the interview about the forces acting in Diagram A, Gavin said that they were “static” forces because “it’s just holding up itself like by the strength of the wood or whatever the materials are”. When asked if the forces had any direction. Gavin said that, “mainly it’s just, well, the load is pushing down, but it won’t go down unless it was going to snap” (Table 1). The interviewer asked Gavin why the load stays there and he answered, “because of the strength of the bridge.” When asked if there is a force acting up on the load he said, “I suppose, the strength of the bridge would be pushing up ... that would even out until there was a larger load here, then it would overcome this one, which is a set load I suppose, and it would push down and it would break.” (Table 1.)

Adam

According to the teacher, Adam is a very good practical student, an independent thinker and worker, he is logical and always produces the paperwork. Adam worked in a group of three with Daniel and JJ for this project and they produced a deck bridge that was the lightest bridge in the class that held the required weight without any deflection. The students had tested several structures in class and worked out the strongest. They then did simple calculations to estimate the costs of the various structures. As a result of their calculations, they also decided to use “I” beams, and only spent \$88.00 in total. Adam, Daniel and JJ decorated their bridge with string rails along the edges and they coloured the deck with charcoal. The students made a mistake when calculating the amount of string they needed to go down both sides of their bridge and then had to buy a second piece. The three students were very proud of their bridge because they thought it was strong and inexpensive. When tested, the bridge did not show any deflection under the weight of the drink cartons.

Adam said that one of the problems they had to overcome was finding a cheap design and that’s why they did the calculations to work out which structure would be inexpensive. Adam felt the important things he learnt were the different kinds of structures, beams and triangles for example, that were alternatives to “just putting planks on planks.” Adam found his mathematics knowledge useful for “totalling things up, working out measurements, strength and things like ratios.”

Adam didn’t think his scientific knowledge was very useful for this project, but said it was useful for other technology studies projects like a Lego racing car project. Adam enjoyed the project because he liked “constructing things, problem solving, always doing research and things like that.”

Adam said that the kind of forces acting in Diagram A are, “just static forces, hitting one place, just going down ... also shear force here [the sides of the bridge], that’s a force down and that’s a force up like that.” When asked to explain further Adam said, “that’s [the bridge’s] just holding it [the load] there, so there is an equal push down and up” (Table 1). For Diagram B Adam explained that it was the same as Diagram A except there was “a heavier load that had bent the bridge” and for Diagram C he said that “the load is pushing down and the spring’s coil is pushing up.” (Table 1.)

Lawrence

Ms O’Reilly described Lawrence as “capable, a good on-the-spot problem solver, but not an academic kid. He doesn’t like the paperwork, I still haven’t got his paper work in.” Lawrence corroborated the teacher’s description when he said, “I enjoyed it [the project], I didn’t like all the paper work because it was way too much and she [Ms O’Reilly] made a big deal out of it.”

Lawrence worked with David and Cain and made a double layered deck bridge with the bottom layer consisting of “I” beams in-between two pieces of plywood and the top layer comprising a layer of Styrofoam with a third piece of plywood. The group found that the “I” beams were the strongest structure from the testing they did and Lawrence explained how they got their idea for the two-layered bridge.

It didn’t take long to make, we “stole” the design from two people’s bridges piled on top of each other. We saw them on the desk while people were putting away their stuff and that’s where we got the idea.

The main problem for this group was that by the end of the project they had spent eight dollars more than they were allocated.

Lawrence said they solved the problem by borrowing the extra money from Ms O’Reilly. Lawrence admitted that the group did not work out how much money their design would cost before they started constructing it. “We sort of made it up as we went along.” The double-layer bridge was very strong and didn’t deflect at all during testing, but the weight of the bridge was comparatively high, so this group didn’t win any prizes.

During the construction of the bridge, Lawrence's group had difficulty adhering the "I" beams with PVA glue. Lawrence said that one important thing he learnt during the project was that "PVA glue doesn't work very well on the plywood for the "I" beams, the glue gun [hot glue] was good with the "I" beams." Lawrence didn't think his mathematics knowledge was useful during the project because the mathematics involved was "fairly simple." Creativity was the aspect of science that Lawrence said was useful for the project, "we sort of painted it, that's the only creativity we used."

When asked about the forces acting in diagram A, Lawrence said that he didn't think there were any forces acting on the load, but there was on the bridge. The interviewer asked him what forces were acting on the bridge and Lawrence replied, "the load." For diagram B, Lawrence thought that there were forces acting on the load, "yes, it's being pulled because this is going down" (Table 1). When asked whether he thought the spring in diagram C was pushing up on the load, Lawrence suggested that "the spring is just sitting there, and this [the load] is pushing down on it a bit. The load is pushing down on the spring, I don't think the spring is doing much at all" (Table 1). Lawrence clarified his explanation by adding, "if it was light, the spring would be real high and the load would fall off and that but, it's all the way down, I don't know how high it is." The extent to which the spring was pushed down was important information for Lawrence to decide whether or not the spring was exerting a force on the load.

Discussion

The results of this case study provide considerable information about students learning science in a technology-based, integrated environment. There is evidence to suggest that the practical, technological experience of the bridge building project precipitated important scientific understandings about forces for the majority of the students. For example, all interviewed students recognised that there were forces in action in diagrams A, B, and C, even though there is no suggested movement in any of these diagrams (Table 1). The results of this study contradict the findings from research discussed earlier that the majority of students of this age associate forces only with movement. Moreover, three of the five students, Gavin, Adam and Steven, clearly recognised that forces were acting in opposite directions in diagram A. Two of these students, Gavin and Adam, identified some kind of balance between the forces resulting in the equilibrium situation of the load on the bridge. In Adam's

words, "so there is an equal push down and up."

In contrast to the encouraging results discussed above, there were indications that some of the students held misconceptions. Lawrence's notion that the load was the force acting on the bridge suggested that he saw a force as a property of a single object (the load) rather than an interaction between two objects. Steven and Lawrence's pondering about the extent to which the spring was pushed down may indicate that they had an anthropomorphic view similar to that described by Viennot and Rozier (1994) where students saw a mass suspended from a spring "as a dynamic conflict between the two objects in which the strongest of them determines a global motion in the direction of its own effort" (p.239). This brings into question Clement's (1987) and Brown and Clement's (1989) use of the spring as a bridging analogy for understanding the forces involved when a book sits on a table.

While it is difficult to directly attribute students' learning to the bridge project, there seems to be something about the project that switched the students on to a scientific understanding of forces. It may have been one specific classroom learning episode, however, it is more likely to have been a composite of several components of the learning environment that contributed to the success of this project. One aspect of the project that made it different from introductory physics courses was its hands on nature. The students had to physically construct the bridges and test the consequences of putting a load on the bridge. During the course of the project, the students were constantly handling the materials and testing them. James discussed the "tension in the wood" and this association with the materials may have been a contributing factor in the students' understanding of the forces in action.

Aside from the practical aspects of the bridge project, the students were involved in complex problem solving. For example, how to increase the strength of their bridge while keeping costs to a minimum. The problem solving process engaged the students in thinking about the materials available and their properties because they had to make decisions about their bridge based on this knowledge. The testing of beams and structures at the beginning of the course assisted the decision making process. The tests were often mentioned by students as they sought solutions to their problems. For example, Gavin and Colby found from their testing that "I" beams were strong, but the triangles were too expensive, so they used "I" beams for their bridge.

Students were encouraged to be creative and a prize was awarded for the most aesthetically pleasing bridge. This created an alternative dimension to the bridge building project that complicated the process of problem solving. The students had to find solutions for the problems they encountered within parameters for strength, cost and aesthetics. This engaged the students in complex cost-benefit analysis. The social aspects of the bridge project were apparent. Students within groups worked together to test materials and conferred with each other to make decisions about their bridge. The social aspects of learning also were evident between the groups, for example, when Lawrence's group's ideas came from observing two other groups' bridges and Steven consulted Adam about the materials his group had used. The structure of the project itself may have contributed to the students' understanding of forces. Students were introduced to ideas about static and dynamic forces early in the project and the practical and social aspects of the course were likely to have reinforced those ideas. Another important aspect of this project was the content knowledge of the teacher. Ms O'Reilly had a background as an architect with a keen interest in engineering science. Her content knowledge was outstanding and this in itself may have been an important factor.

Although some of the students interviewed from this classroom demonstrated surprisingly good understanding of some of the scientific principles associated with the bridge project, three of the five students did not think their scientific knowledge was useful during this project and one other student identified creativity as the only aspect of science that he used. For example, Steven discussed several ways in which he used his mathematics knowledge during the project but said, "I don't think we did as much science." Not only was there considerable science about forces implicit within this project, students were involved in investigating different structures in a scientific way to help them make decisions about the kind of bridge they would make. Gavin was the only student who said that science was useful for helping him with the investigations. Adam recognised that he was doing "research" when he did the investigations and he said that he liked doing the research, but he did not associate the investigations with science, "I don't think [science was useful] so much for this project, but for some of the other projects."

One possible explanation for this lack of recognition of the science aspects of the technology project is that the students saw science more as a content oriented subject rather than a skill or process oriented subject. Most of the students recognised the process of doing mathematics, however, few students recognised when they were doing science.

The findings of this study were very positive in terms of the students' understanding of the forces associated with the bridge and load structure, especially considering this was not a science class, but a technology class. The results show a wealth of potential scientific learning experiences that may possibly address well recognised alternative conceptions held by a large number of students. While recognising the difficulties in attributing outcomes to particular teaching strategies, there are several aspects of the course that may have contributed to the students' understanding. These included the hands-on aspects of the bridge construction, complex problem solving, testing of beams and structures that assisted decision making, attention to aesthetics, social interaction within and between groups of students, the structure of the project and the background knowledge of the teacher. It does seem that the pedagogical features of this kind of project do offer the potential for enhanced learning of science concepts.

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