Teachers, Turtles, and Gravity

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Abstract

Four cohorts of preservice science teachers were examined to determine their scientific content knowledge of gravity, and to look for evidence of emerging pedagogical content knowledge related to their classroom teaching of gravity in the senior secondary school curriculum. A fine-grained, semi-structured interview that made extensive use of media and computer-based probes, was used to collect detailed data about a narrow range of gravitational contexts relating to orbital motion and planetary gravity. Logo played a significant role in exploring the participants’ conceptual difficulties.

Keywords: pedagogical content knowledge, physics, gravity, Logo

1. Introduction

This paper describes how Logo was used in part of a study to develop an agent-based PCK-enhanced software environment for improving preservice physics teachers skills in teaching physics. The study examined preservice science teachers’ understandings of gravity in orbital and planetary contexts, as well as the ways in which they represented their understandings of gravity to their students — an important element of their emerging pedagogical content knowledge (PCK) — the ‘craft knowledge’ of teachers (Shulman, 1986a; 1986b; 1999). PCK is something that teachers, arguably, have to develop or acquire in parallel with their development of subject matter knowledge. In contrast to ‘cognitive’ or ‘developmental’ studies of physics learners, the essence of this study of preservice physics teachers was about the dichotomy between ‘knowing’ physics — in the formal sense of understanding concepts and laws (and being able to use that knowledge to solve problems), and being able to teach it effectively, because the two are not necessarily synonymous (e.g., Magnusson, Krajcik, & Borko, 1999, p.112).

Much of the traditional research in science-teacher education has been based on the assumption that teachers’ and students’ problems with teaching or learning science, and especially physics, are largely due to partially or incorrectly formed understandings of the relevant concepts and laws, or of their relationship to one another. Such research, however, essentially focuses only on scientific content knowledge acquisition, development, and use. Shulman (1986a; 1986b), however, suggests that PCK is an equally important focus for educational research, raising the possibility that it might equally be the nature and quality of teachers’ PCK that is the cause of many of the observed difficulties in science teaching (and perhaps, therefore, of their students’ learning of science), rather than content knowledge, and provides a framework for examining this dichotomy. This study adopts Shulman’s position by examining both the pedagogical and conceptual difficulties that preservice science teachers have with a particular gravitational context of the Victorian (Australia) senior school physics curriculum (VBOS, 1997). The study addressed the two specific questions below. Logo was used to both create probes and to facilitate student modelling in examining these questions.

What is the nature of the participants’ PCK and content knowledge of gravity?
What is the nature of a pedagogical knowledge-base that could inform the development of software (PCK-enhanced software) that could be constructed to support and facilitate the development of both PCK and content knowledge in this area of the curriculum?
2. The Context

I frequently found serious misunderstandings, and weak, or inadequate explanations and representations of the concepts of gravity and gravitational field in undergraduate preservice physics-education students for whom physics was a minor subject in their B.Ed (Secondary) degree (i.e., comprising only a three year sequence of study) (cf. Dykstra Jr, 2000). First, in schools they were often unable to give satisfactory answers in response to simple questions from students, preferring instead to rely on formulae and graphs (cf. diSessa, 1993, p1; Sanders, Borko, & Lockard, 1993). Second, in addition to their inadequate explanations, I observed many examples of incorrect statements, subject-matter deficiencies, invalid analogies and metaphors, and wrong ‘factual’ information being used in their classes. The following dialogue from a student teacher’s year ten-science lesson on ‘force’ is a salient example of the type of problem that was common in the junior school context. The student, ‘Suzie’, has asked a question about falling objects after viewing an episode of the television cartoon series The Simpsons the previous evening, in which she saw the character ‘Homer’ make an apparently impossible leap across a gorge, and was puzzled about whether such a leap was possible or not, and why:

Suzie: ‘Sir, why DO things fall down?’
Preservice Teacher: ‘Ah… um, because of gravity.’
Suzie: ‘Yeah, that’s what Dad said.’ replied Suzie.
Preservice Teacher: ‘Good! Are you sure you really understand?’
Suzie: ‘Its cool - gravity does it.’ was Suzie’s reply.
Preservice Teacher: ‘You’ve got it!’ said the teacher.

After the class, I asked Suzie to explain what gravity was, or how it acted, or if she could explain why the leap she saw on television was impossible. She was unable to do so, but seemed happy with her knowledge that gravity made things fall down. I also asked the preservice teacher if he thought that Suzie understood ‘why things fall down?’ He felt that she did! I left, feeling disappointed for both of them, determined to identify ways for them to improve their knowledge of this aspect of physics. My concerns increased as I supervised their specialist physics practicum during which they were teaching the gravitational topics in the Victorian Certificate of Education (VCE) senior physics syllabus. The central ideas and context of the unit are related to Newton’s law of universal gravitation, gravity, gravitational field and planetary systems. Even in this specific context, the majority of the preservice teachers were uncertain about the application of basic physics concepts to planetary situations. For example:

Student: ‘What’s a gravitational field got to do with gravity?’
Preservice Teacher: ‘It’s where you find gravity.’
Student: ‘What do you mean?’
Preservice Teacher: ‘There is always a gravitational field between two planets.’
Student: ‘Oh, OK.’

In this dialogue there is potential confusion over where a gravitational field exists, no mention of their pervasive nature, nor of their form. By omission it has sown potential seeds of confusion between force, field, and acceleration (i.e. gravity). Such partly correct answers were symptomatic of the students that I observed. In another discussion on orbital motion, one preservice teacher told the class…

Preservice Teacher: ‘Newton’s law of gravity only works for circular orbits.’

At the same time their quantitative knowledge of the same situations was generally very good (cf. diSessa, 1993, p.1) — they could describe how to solve the relevant mathematical problems in the text, and described the use of the necessary equations quite effectively. It was this disconnectedness of the two modes of their teaching that finally convinced me that a way to reconcile the differences had to be found.

3. Pedagogical content knowledge

Shulman’s PCK is based on the proposition that content knowledge (e.g., of physics) does not provide an adequate preparation for teaching — that learning more science, or knowing it ‘better’ does not necessarily produce a better science teacher. PCK is a knowledge base for teaching (Grossman, Wilson, & Shulman, 1989) that encompasses the ways in which teachers’ pedagogical knowledge and skills interact with their
content knowledge to produce contextually and developmentally appropriate teaching strategies, explanations and descriptions of subject matter. For example, in junior science, acceleration is often described as a change in speed, only later to be redefined as the time-rate of change of velocity when the students have acquired these further concepts. The teacher has simplified and contextualised the definition to a point where it is incorrect, but which is deemed appropriate for the students’ current level of understanding. PCK is a utilitarian (as opposed to theoretical) construct that has been conceived of in different ways by different researchers. All, however, share the fundamental notion of an intimate and interactive relationship between subject matter knowledge and PCK: for teachers, the two coexist seamlessly, and each supports the other. PCK is currently considered to be an important knowledge base for science teacher preparation (e.g., NSTA, 1999; Tobias, 1999; Veal & MaKinster, 1999, p.1), and the focus most likely to impact on teachers’ practice. Magnusson, Krajcik, and Borkos’ (1999) model of PCK for science teaching was adopted for this study because it is arguably the most refined model currently available for use in science education. The PCK focus of this study was on topic-specific PCK (T-PCK) — teachers’ knowledge of specific strategies that are useful in helping students comprehend specific science concepts. This has two components — activities and representations. Activities are the educational learning activities that are used to help students learn about the content. Representation refers to:

Ways to represent specific concepts or principles in order to facilitate student learning, and knowledge of the relative strengths and weaknesses of specific representations.

The ability to invent representations to aid students’ understanding of specific concepts or relationships.

If teachers cannot make effective use of such representational forms, then even an excellent grasp of subject matter knowledge is unlikely to be translated into clear and effective pedagogy (Yager, Hidayat, & Penick, 1988, p.174) In this study, the participants’ PCK — verbal and written representations of gravity, were examined (along with their content knowledge of physics) through the use of a variety of probes — video clips, computer-based simulations, and computer microworlds. This paper concerns itself only with their representations of gravity, and the use of Logo in exploring its nature.

4. Modelling gravity in Logo

Figure 1 depicts the basic context for Logo’s use in this study — probing participants’ understandings of the gravitational field structure around planets.

Both StarLogo (Resnick, 1997), and Alexandrov and Soprunovs’ (1997) Field extensions to MicroWorlds, allow modelling a gravitational field by defining an acceleration vector that tells a turtle in which direction it should move, and for how far, as in Figure 1. ‘Inertial’ models (e.g., McCauley, 1984), however, use vector addition – an inertial ‘move’ followed by a radial gravitational ‘fall’ (or vice-versa as the result is the same) as in Figure 2, that are calculated for each time interval.
StarLogo’s patches, however, provide the opportunity to create both a data structure that better reflects the continuous nature of fields, and powerful visual representations of them. It’s particularly useful for implementing static field models (as in Figure 1) with the magnitude and direction set in the patches, and a visual representation of field strength created using Newton’s law of universal gravitation along with `scale-pc` (as below) which may help users to develop some understanding of the nature of the field they are examining.

```
casetgravity G scale-pc red gravity 1 500
  to G
    output Planet/((distance-NOWRAP 0 0) * (distance-NOWRAP 0 0))
  end
```

This code fragment was used to create the visual representation in Figure 3.

Resnick (1997) uses `sum-of-turtles` to dynamically calculate the gravitational field due to a number of moving masses, providing an effective generic solution to multi-body contexts. The preliminary planetary probes were developed using a modified version of Resnick’s gravity procedure with two turtle breeds — asteroids and planets. To create a simple microworld in which the field around a planet was modelled, as in Figure 3, simply required that asteroids were of variable mass, and free to move, whereas planet turtles were stationary (as a convenience for the simulation). With this simple adaptation, it’s easy to simulate binary and ternary systems by fixing planet turtles on the plane, and allowing asteroid turtles to move under the dynamically calculated resultant gravitational field. The latter is important, as it allows the close approach of asteroids to create local, transient, gravitational interactions that may significantly affect the acceleration of the closely interacting asteroids – something that is effectively ignored in the static-field model’s first order approximations. In simulations with a large number of asteroids, or with large masses in close proximity, this effect can be quite significant, causing deviations in the asteroids’ trajectory. An intrinsic advantage of this approach is that there is very little additional coding required to add extra planets, as the gravitational field from each mass particle is automatically calculated.
5. Uniform and Linear Fields

Cartoons and a simple projectile microworld, showing a basketball being thrown, were used to probe understanding of uniform fields (e.g., where gravity at the Earth’s surface is taken as \( \approx 9.8 \, \text{m.s}^{-2} \)). The three categories of responses elicited with the microworld are shown in Figure 4.

![Figure 4: Forces on a ball in a uniform gravitational field.](image)

The first two posit that falling elicits some kind of reaction force from the Earth that slows or pushes the ball upwards as it reaches its apogee. These responses demonstrated confusion about Newton’s third law, perhaps being indicative of an active-force model in which force acts selectively on objects as they move. The third category presents the correct Newtonian model, where the only force acting is gravity, which causes a constant acceleration (neglecting air resistance). Similarly, others described an animistic model in which the ball selects its gravitational interaction, or an ‘active force’ model in which gravity starts to act when the ball falls:

…It suddenly hits a point where it goes ‘nuh, I’m slowing down’ or something, and decides it’s going to start acting under gravity.

A mass-dependent acceleration was common, with many students persisting in the belief that heavier objects fall faster, e.g.,

It depends on their weight, but generally they’re going to fall at the same sort of speed if they have the same sort of mass.

When they were challenged to model their responses in Logo, only those holding a Newtonian view were able to do so, using a simple `f \( \downarrow \) v0-\( g \times t \)` instruction embedded in a MicroWorlds turtle. The other students were unable to produce any functional models to explain their views, mainly because they had no conception of the origins and action of their upwards ‘gravity’ or reaction force. Subsequently, some of them resolved their misconceptions through examining the ‘correct’ code, and discussing its design with its creators. Others felt that MicroWorlds was too hard to learn to use, and to learn from, in this way!

The Simpsons cartoon probe presented a set of dynamics events, with the character Homer rolling down a hill on a skateboard, to be launched off a cliff. As he flies through the air, he performs an ‘ollie’ on the skateboard, and then falls suddenly. Their conceptual problems manifested themselves in various ways, e.g., the apparent use of a phenomenological ‘support or fall’ model (cf. Bliss, 1989):

There is no surface after the cliff, so it’s causing him to fall.

As before, the students were generally unable to model their erroneous understandings. Curiously, the unfamiliar context made the Newtonian students much less certain about applying the ideas they had used in the previous example.

The students understandings of the variation of gravity with distance were examined with both ‘linear’ fields (where field strength varies linearly with distance) and inverse-square fields. The linear field model created a graphical representation of the field as in Figure 4, where gravity varies linearly left to right. The visible gradient can be interpreted in many ways by students, but is intended to show that the gravitational field strength varies horizontally. There is no explicit evidence that the gradient is linear.
Such simple representations can be surprisingly powerful probes because students are often confused about the relationship between a visual gradient and the nature of the underlying causal field, often confusing the former with the presence or absence of gravity somewhere, as if it were an object, rather than a field:

Int: Can you describe the gravity represented here?
Stu: Easy! It’s over there… because the lines are accelerating towards it!

Students were required to analyse the motion of the three particles that move in the field in order to deduce the nature of the field. However, this is not as simple as it seems, because one of the particles behaves differently to the others — as if its mass were zero. The other two particles accelerate to the right, suggesting that a force (gravity) acts in that direction. Careful analysis of the paths reveals that the acceleration is greater than expected for a uniform field, but most students didn’t think to check this. The majority of students assumed it was a normal (uniform) gravitational field.

6. Radial Fields

Planetary gravitational fields are the prime focus VCE curriculum. However, as in the examples above, students are confused about what these representations imply about the causal gravitational field they model, particularly in the case of binary systems. The student model in Figure 5 suggests that the student has difficulties with superposition and cancelling of forces, and is confused about equipotential surfaces and field ‘lines’.

Int: So these are field lines?
Stu: Yeah, … It gets to a point where they shoot out and cancel each other out. And if they are equidistant I guess that’s why …, they are not going to be sort of repelled, um attracted, in to their field sort of lines.
Int: If it gets attracted into one of those field lines, will it move along one of those lines?
Stu: Yeah. It gets attracted to … either one of the planets.
Int: So what is the relationship between those lines and gravity?
Stu: I don’t know …Um …gravitational field lines.
Int: So if an asteroid is attracted into one of those field lines, does it move along the line?
Stu: Yeah! Oh it could bend in perhaps…

Most of the ‘Newtonian’ students, however, were able to correctly describe the field in Figure 5 in terms of superposition of forces from the two planets, as in Figure 6. Their ability to use standard representational forms helped them to do so, in marked contrast to many of the students with conceptual difficulties, who generally could not create an effective representation of what they were attempting to describe — perhaps because of their confusion with the underpinning concepts.

Figure 6: Student description of the field structure in terms of superposition of forces.

7. Conclusions

This study confirms Cochran and Jones’ (1998, p.243) findings that preservice teachers commonly show little integration or stability in their subject matter knowledge, and are unable to make links to pedagogical matters, because of a lack of deep understanding of content and context. In this study, the students’ problems may have been exacerbated because, in all but one case, they were teaching out of their primary area of expertise — the so-called ‘out of field’ problem. When teachers teach out of field, they are less confident about content and the use of examples, models, metaphors etc. — the essential components of PCK. However, Dykstra Jr. argues that the nature of tertiary science education itself is responsible for the widespread misconceptions held by tertiary graduates and the general public:

What we have been finding consistently is that student conceptions hardly, if at all, change as a result of normal (university & school) science instruction. (Dykstra Jr, 2000)

He argues that this is because science education is conducted by the graduates of a system more capable of passing on their ‘ignorance’ rather than engaging students in the active pursuit of knowledge, a self-propagating ‘cycle of ignorance’ (cf. Nicholson & Underwood, 1995)

School as it is today clearly is more training than education. It suppresses, de-skills, dumbs-down students from the capacities we are born with. This enterprise is conducted largely by suppressed, de-skilled, dumbed-down products of itself. (Dykstra Jr, 2000)

While this is an extreme view, his concerns about science education focusing on training future scientists at the expense of ‘dumbing-down’ most students — as is apparently the case with the participants in this study, need to be embraced by the science education profession. While his conclusions are alarming in terms of graduates’ knowledge of scientific content, the implications for the teaching profession are profound — it’s almost impossible to teach effectively when the underpinning content knowledge is weak (the basis of Cochran’s concerns). In terms of PCK, the implications are equally profound. If teachers don’t understand
the nature of the concepts they are representing, then how can they both identify and explain the ‘best’ model or approach to use with their students? Clearly, the majority of students in this study will have great difficulty in explaining basic scientific concepts to their students and, if this study is indicative, will be unable to identify and use appropriate pedagogical methods to facilitate student learning.

What is required is a restructuring of science education pedagogy to focus on the development of expertise rather than acquisition of scientific content knowledge. Hestenes (1995, p.63) argues that this has to be led by a software-based curriculum (as opposed to the use of software in the curriculum), in which modelling, simulation, and cognitive engagement are the primary focus of learning. While this is arguable, it is significant that globally, ICT, and particularly the use of Logo, is not a major component of teacher education preparation, and there is clearly a question of how to integrate the effective use of ICT on teacher education. The challenge for the Logo community, perhaps, is to both publicize a wide range of ways of using Logo in teacher education across all curriculum areas, in ways that give preservice teachers the awareness, knowledge, and skills to make effective use of it. In particular, preservice teachers additionally require the purposeful and concurrent development of PCK so that they can seamlessly relate pedagogy and content to produce authentic learning experiences and appropriate representations and explanations for their students. Logo-based environments have great potential for use in science education for student modelling, cognitive engagement, and representational forms, but little thought has been put into how Logo-based environments might be used to facilitate the development of pedagogical expertise, yet little is being done in this area. Perhaps the ongoing fascination with Logo’s inherent ‘cognitive’ focus has distracted attention from the needs of teacher educators as learners, rather than as users, or perhaps ‘trainers’ in Dykstra’s terms — a similar criticism to his reproach of the science-education community.

This brief paper has ranged over some elements of a multi-discipline study that concludes that preservice science teacher education needs significant reform in its approach to both content knowledge and pedagogy, particularly PCK. Logo-based learning environments have significant potential to facilitate effective reform in both areas of teacher preparation, but are commonly (mistakenly) seen as reflecting an outdated approach to learning, especially when compared to emerging agent-based learning environments. It’s time to think about how to use Logo in teacher education to promote expertise (not just in ‘using’ Logo), and what a primary focus on PCK implies for the ways in which Logo is used in preservice teacher education!

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