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Journal Owner:

Dr. Esma USAK

Mailing Address:

Mareşal Cakmak Mh. Göktug sk. No: 23/4
Sincan, Ankara – TURKEY
E – mail: ejmste@ejmste.com

Editorial Office:
Mehmet Fatih Taşar (**Associate Editor**)
Gazi Universitesi, Gazi Eğitim Fakültesi,
İlköğretim Bölümü,
K Blok 228, 06500, Teknikokullar,
Ankara – TURKEY

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EDITORIAL

M. Fatih Taşar, Associate Editor
Gazi Üniversitesi, Ankara, TURKEY

Dear readers,

We are glad to introduce the last issue of this volume. There are eight research articles representing the usual diversity of papers published by EURASIA. The diversity comes from both the regions that the papers are emerging and the fields that they represent. I hope you'll find them useful and relevant to your endeavours.

I wish to take this opportunity and annouce the second call for papers for the 2009 Conference of European Science Education Research Association (ESERA) which will be held in Istanbul between 31 August and 4 September. Please visit the conference web site www.esera2009.org to find our more about the conference and the events that will be taking place.

Another announcement is that Professor Reinders Duit retired from the IPN – Leibniz Institute for Science Education. He has been one of the most influential figures in the history of science education in the last thirty years or so. He contributed to the conceptual learning and conceptual change literature immensely. Another aspect of Prof. Duit is that he collaborated with colleagues from around the world in his endeavors and has been widely known in the international arena. We wish him a happier long life and expect to see his contributions at a more influential level in the years to come.

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'Now This is What Should Have Happened…': A Clash of Classroom Epistemologies?

Michael Allen
Brunel University, Uxbridge, UNITED KINGDOM

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Current school science curricula attempt to reflect contemporary constructivist-provisionalist related epistemologies as accepted by professional science. It is argued that conversely, the effect of science education is the creation of pupils holding naïve-realist epistemological beliefs, largely inductivist-positivist absolutists who chase an irrefutable 'right answer'. This outcome has unwelcome consequences:

1. Encouraging positivist mind-sets during school science practical work that trigger confirmation bias and other deviant evidential attitudes.
2. Philosophical inconsistency creating epistemological confusion with a tendency towards positivism that continues into higher education, and perhaps beyond. This forms a significant barrier to science learning and impacts on the quality of scientists within the workforce.

Solutions are offered but as things presently stand, significant change is deemed unlikely. Discussion of these issues is timely in the light of the recent introduction into English secondary schools of a teaching scheme that articulates a post-positivist view of the nature of science, in the form of a *How Science Works* strand.

Keywords: Literacy, Religion, Science, Sociocultural, Superstition

INTRODUCTION

Real science is the pursuit of provisional theories. Contemporary scientists seek to grasp the reality of natural phenomena by challenging self-constructed hypotheses with current empirical data, and so theories have to be impermanent in the event of a later experiment revealing an alternative theory as being more likely to represent that reality (Kuhn, 1996). A school science curriculum aims to foster a conventional scientific attitude within children (Gott and Duggan, 1996; Millar, 1991), as the English Nuffield scheme of the 1960s put it, being *scientist for a day* (Fairbrother and Hackling, 1997). Citing instances from the UK system, this article intends to show that science education has failed in its quest to turn pupils into authentic constructivist scientists, and is actually producing antithetical inductivist-positivist experimenters. In addition, it is argued that contemporary science education would never be likely to produce constructivist 'little scientists' as other aims of the curriculum interfere with the process, manifesting as a clash of epistemologies. Solutions are suggested, but as things presently stand could only make the best of a flawed system.

As well as introducing pupils to the acceptable conventions of experimentation school science also aims to deliver a body of 'right answers', as delineated by Attainment Targets 2-4 of the English National Curriculum (Osborne and Collins, 2000). In this respect, school science contrasts with professional science in the way it endeavours to transmit currently established theories as if they were irrefutable, so assuming the naïve-realist epistemological stance reflected by positivism, viewing pieces of knowledge as hard, fixed external entities. This rejection of a pluralist view of science that echoes a constructivist-realist epistemological standpoint where knowledge is considered an internal, human construction that is a

Correspondence to: Michael Allen, Dr, Lecturer in Science Education, School of Sport and Education, Brunel University, Uxbridge, UB8 3PH, UK.
E-mail: michael.allen@brunel.ac.uk

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product of free will, is necessary otherwise pupils as novice scientist-thinkers may erroneously end up making up their own minds about phenomena and ignore the scientific position, becoming solipsists. The contexts of professional science and school science are diverse in this respect – the former allowing pluralism accompanied by peer debate that determines the provisional 'best construct', the latter perhaps paying lip service to pluralism, but ultimately siding with only a single absolute answer – that which external examination agencies see as being correct, who in turn reflect the current social consensus of the scientific community.

In 1975, Driver explained how the two aims of encouraging an authentic scientific method and delivering a set body of knowledge are incompatible - and the same is true today - within school science the parallel encouragement of positivist and constructivist attitudes means that two conflicting epistemologies coexist in a state of uneasy peace. Pupils used to a diet of spoon-fed, absolutist science commonly have difficulty switching to pluralist mode during novel investigations where a right answer is initially unknown, and 'Miss, have I got this right?' becomes a frequently heard appeal. Such a dualist structure means teachers send mixed epistemological messages by requiring pupils on the one hand to be provisionalist, constructivist proto-researchers who will fairly collect and interpret data during enquiry-based investigations, faithfully rejecting hypotheses that observations and measurement refute to form tentative conclusions, though in a different context such as with illustrative practicals that are designed to verify the textbook, insist they have performed adequately only when their data support a naïve-realist, positivistic, unassailable 'right answer'. To this latter end practical lessons are generally set towards producing the orthodox scientific response (Kirschner, 1992), and there are strong drivers presently in place that make pupils conduct their science positivistically in order to acquire the right answer during coursework and exams (Hodson, 1993). This notion of there being one right or scientifically acceptable answer has unsurprisingly led to shrewd students attempting to improve their grades by manipulating apparatus, methods and results to ensure they obtain that answer, behaviours which have been tolerated (Toplis, 2004) or perhaps even encouraged by teachers swayed by GCSE examination league tables.

> "Performance may also be affected if pupils believe they know 'the right answer' and see this as a way of obtaining good marks. They may then write a convincing report based on previous ideas ignoring their own data, whether or not the data agree with their prediction of what the right answer should be and regardless of the teacher's guidance. Again we have recently seen evidence in the UK that some pupils are purposely gearing their work to achieve particular assessment goals" (Gott and Duggan, 1995, p61).

Espousing the idea of a standardised result is something that all science teachers do at some stage, and since a good deal of practical work involves the verification of facts covered during theory lessons, this helps foster pupils' desires to 'get the right answer', as stipulated by substantive content. If practical lessons fail to do this, which may happen due to inadequate apparatus or technique, teachers often conclude by stating 'this is what ought to have happened' (Simon and Jones, 1992, p3). Claxton (1986) echoes this sentiment, as the common practice of teachers stating 'your results are incorrect, but don't worry, this is what you should have got' undermines learner confidence in performing experiments and in science generally. Pupils may respond with 'is this what ought to happen?' or 'have we got the right answer?' (Driver, 1975; Wellington, 1981), or even 'if the answer was known anyway, and we always get the wrong result what is the point in doing the experiment?' (Claxton, 1986). Hence for these learners data collection becomes a chore as outcomes have been determined in advance, and a lack of intellectual challenge focuses students on getting the right answer rather than carrying out genuine scientific enquiry (Fordham, 1980). Roth (1994) denigrates 'cookbook practicals' as having low cognitive demand, precluding reflective thought and concentration. Roberts and Gott (2006) similarly note that the House of Commons Select Committee recently commented that GCSE science coursework such as the familiar generation of data to illustrate Ohm's law is tedious and dull for both pupils and teachers, having little educational value.

The presentation of science as a blend of two disparate epistemological positions does not help pupils to see the subject as a holistic entity. Most of the experience of school science education involves exposure to a set of dogmatic right answers which are required to be learned in order to pass formal examinations, for instance the variety of factors that influence the rate of a chemical reaction. Parallel with and subsequent to this epistemologically naïve-realist delivery of facts, pupils may be required to carry out a scientific enquiry task that 'investigates' the effect of variables such as reactant concentration, temperature and particle size on the rate of reaction when marble chips are added to dilute hydrochloric acid. The gestalt shift required when switching between already knowing the facts so therefore the ending, and then suddenly working in an epistemologically constructivist-realist, thus pluralistic mode in order to fairly consider all outcomes must perplex pupils, particularly the less able, consequentially prompting comments from insecure learners like those expressed in the previous paragraph.

In addition to these immediate issues of fraudulent behaviour, routine experimentation and epistemological confusion, there are more lasting, conceptual repercussions of the promotion of positivistic methods, discussed next.

Cognitive implications of delivering a positivistic curriculum

The idea that a right answer exists creates expectations within the minds of participants in the appropriate direction, and these expectations can be elicited during predictions. Properly conducted science should allow for the 'bracketing' of these expectations during the collection and consideration of data (Austin, Holding, Bell and Daniels, 1991), although famously some scientists have allowed their preconceptions to govern data collection so producing results that confirm desirable inferences – the Fleischmann and Pons cold fusion debacle (Huizenga, 1993) springs to mind. This *experimenter-expectancy effect* can hold considerable sway particularly when the stakes are high (Rosenthal, 1966). A long-term study of the expectation biases displayed by school pupils during practical lessons related how the wish to find a predetermined answer can initiate a wide variety of scientifically improper behaviours, or *ERO*s, including the fabrication of data, ignoring anomalies, and rigging apparatus to generate a positivistic right answer (Author, 2006). Findings from this research have suggested there are chronic problems inherent in teachers presenting scientific theories as the products of an inductivist-positivist process that infers the existence of an absolute right answer, with five general areas of concern.

1. Rejection of the scientific conception due to holding a misconception theory

If pupils anticipate a right answer that constitutes a non-scientific theory, what they think to be the right answer is actually wrong. Nott and Smith (1995) say that unfair manipulations such as the rigging of students' apparatus are justified in order to avoid the gathering of refutory data, which may be satisfactory if it is the scientific answer that is believed by the observers, but the authors fail to note that this is problematic when learners are aligned to a misconception theory. In this instance, valid data that support the correct view may be rejected as anomalies due to EROs, and so misconceptions will be reinforced. The author's ERO study (2006) found that misconceivers would happily continue to reject any results that refute their personal theories until 'forced' to acknowledge otherwise by mounting peer pressure; such social influences, though purposely present in the particular lessons created for the study, may be lacking with traditional science practicals.

Additionally, believing a scientific theory and knowing the *right* answer but mistakenly observing a different phenomenon can result in EROs where pupils have ignored valid data. An example of this would be applying the scientifically correct concept of different masses falling with equal velocity to objects dropped by parachute, where the action of air resistance becomes a significant variable; heavier objects should fall more quickly, though a desire to confirm the equal-velocity theory may cause EROs that miss the reality of the event. Roth, McRobbie, Lucas and Boutonne (1997) describe how previous, similar demonstrations interfere with interpretation of a current demonstration.

2. Promoting a lack of differentiation between theory and evidence

There exists a natural tendency for learners to believe evidence and theory are one in the same and use the terms interchangeably, with conclusions often given in place of results (Foulds, Gott and Feasey, 1992; Gunstone and Champagne, 1990; Kuhn, Amsel and O'Loughlan, 1988). If the two do not match unease is felt, analogous to travel sickness being a result of a lack of correspondence between stimuli from the eyes and inner ears, and there emerges a cognitive drive to reduce any disparities between them. Encouraging observers to collect data that only support a single, favoured hypothesis could nurture this tendency, with observations having the status of predetermined entities; Fordham (1980) states how such experimenting becomes a chore for participants. This approach can only blur the boundaries between empirical evidence and explanatory theory, with a further consequence being point 3, next.

3. Causing a shift towards preferring theory over evidence

During practical lessons learners are expected to behave as *bona fid*e scientists, fairly acknowledging a variety of data that may support or refute a hypothesis. However, when pupils are asked to compare evidence to theory, disproportionate importance is often allocated to theory (Austin *et al.,* 1991; Gunstone and Champagne, 1990; Lubben and Millar, 1996), with empirical data sometimes being discounted entirely (Foulds *et al.*, 1992). The ERO research (Author, 2006) provides examples of the favouring of theory in the form of preconceptions over experimental results, for instance during interviews 8/10 pairs admitted to allowing preconceptions to govern data collection or inference making. One year 8 (age 13) pupil was asked to explain why he had recorded a particular result and offered a theory statement, not referring to his data at all, "because we *thought* that the smaller the rod,…it will take in the heat" (Merdeep). If teachers encourage a view of the mechanical confirmation of an irrefutable right answer this derogates the value of practically derived evidence.

Gilovich (1991, p4) describes how irrational believers of ESP routinely ignore evidence that contests the phenomenon, "...there is a notable gap in all cases between belief and evidence." The denial of information that we do not agree with not only makes us poor scientists but unreasonable beings generally, and a liberal attitude towards the treatment of evidence lays us open to the persuasions of confidence tricksters and the embracing of desirable though evidentially unfounded pseudoscientific / supernatural matters such as astrology, extraterrestrial visitation, extant prehistoric creatures, cults, ghosts and crop circles. A recent drive, supported by a few academics, to promote creationism in the English school science curriculum represents an instance of complete negation of scientific evidence in favour of preconceived, irrefutable (religious) theory (Farrar and Shepherd, 2006).

4. The creation of serial-EROers

Allowing pupils to bend the procedural rules and selectively sort data so that a right answer may be confirmed sends out the wrong messages. If a practical activity is carried out, as many are in school science, for the purpose of confirming a well-known, established theory, having a predetermined outcome is unavoidable; when pupils know that only one hypothesis out of several alternatives is correct, any data that support disfavoured alternatives are bound to be negated, and ERO behaviours ensue (Author, 2005). If activities are commonly presented in this manner then improper behaviours will become part of pupils' repertoires. Rigano and Richie (1995) note teacher admissions of their own ERO-driven manipulations, and these individuals have probably absorbed the ERO culture during exposure to the similar behaviours of their science teachers during childhood.

As well, professional scientists can demonstrate improper confirmation bias, revising procedures until results that agree with their theory are gained (Greenwald, Pratkanis, Lieppe and Baumgardner, 1986); similar behaviours are known in the medical and psychology professions. Taken to the extreme, such EROing by scientists can culminate in serious fraud, when the desire for supporting evidence is so strong that results are altered or invented, papers published and invalid, often spectacular claims declared.

5. The continuation of positivist-related epistemological belief into tertiary education

> "Naive epistemological beliefs have long been identified as a major impediment to the achievement of conceptual change in science education" (Theormer and Sodian, 2002).

Significant numbers of science undergraduates and postgraduates have been shown to hold positivist-related naïve-realist views of the nature of knowledge (e.g. Hammer, 1994; Theormer and Sodian, 2002), including the belief that scientific knowledge is certain and absolute. Such students have difficulties in understanding the relationship between theory and evidence (see points 2 and 3, above) and fail to restructure theory in the light of new, anomalous data, potentially and subsequently influencing the quality of professional scientists/persons in occupations allied to science within the workforce.

To sum, despite teachers' common desires for pupils to engage in authentic and contemporary constructivist scientific thinking, naïve-realist epistemology that is implicit in science curricula and reflected in teachers' everyday behaviour during both practical and theory lessons guarantee that pupils will too behave as positivist right answer chasers. This outcome has unwelcome ramifications in two related though distinct ways:

1. Encouraging positivist attitudes during school science practical work.
2. Philosophical inconsistency creating epistemological confusion with a tendency towards positivism that continues into higher education, and perhaps beyond.

Improving the situation

It is of no surprise with that content-driven curricula, naïve and debunked positivistic approaches to science particularly inductivism that reflect realist epistemology continue to dominate in science classrooms (Hipkins and Barker, 2005), and since a teacher's personal epistemological leanings are probably implicit or unconscious any philosophical clash would go unnoticed. In any case, teachers who might be aware of the mixed messages that they convey to pupils would find the inflexibly dichotomous structure of the science curriculum forgoes any attempt to align philosophical inconsistencies. Despite previous work demonstrating the favourable effects of a long term, consistently constructivist science programme in changing positivist attitudes (Smith, Maclin, Houghton and Hennessey, 2000), at present, remedies might ultimately be limited to merely acknowledging the dualist character of the curriculum, continuing to compartmentalise philosophical approaches to their corresponding constructivist or positivist activities, and resigning ourselves to turning out yet another cohort of epistemologically-obsolescent, positivist 'little scientists'. The remainder of this article assumes this stance of 'making do' and suggests ways in which the impairments linked to positivistic attitudes in the form of right answer chasing might be limited.

Disquiet in relation to a dualistic science curriculum has been reported elsewhere in the literature (e.g. Osborne, Ratcliffe, Collins, Millar and Duschl, 2001), and currently a re-consideration is appropriate in view of the recent inclusion of a *How Science Works* strand into GCSE syllabi that promotes a post-positivist view of science, discussed in greater depth later in the article.

Discouraging the careless disposal of anomalous data

Findings from the ERO study (Author, 2006) show that one of the most common evidential misbehaviours (38%) was the rejection of data and repeating the experiment in a different way. Thoughtless discarding of negative data needs to be discouraged in favour of the reasoned justification of rejections, for instance on grounds of truly invalid method. Pupils need to be aware that it *is* acceptable to ignore their results, but only with good reason. Fairbrother and Hackling (1997) concur with this approach, and state that when judging if an experiment works one should not think about if it has delivered *the* right/wrong answer, but see if it gives *an* answer that can be defended, by checking, as you would a well oiled machine, the whole thing fits together and runs properly. Gunstone (1991) recommends an increased awareness of the biasing effects of preconceptions:

> "...use chosen examples of observation and subsequent discussion to help students realise the effect of their own theories on their observing and referring from observing, the importance of discriminating between observation and inference, and the claims which can validly be made from observation. The POE [Predict, Observer, Explain] strategy is a powerful approach here because the use of predictions with reasons can so readily bring out personal theories prior to observing" (ibid., p73).

Millar (1989) suggests that in order to demonstrate to learners the relationship between expectations, data and theory, i.e. making observations and their subsequent interpretation, half a class should be asked to provide empirical evidence to support one theory, while the other half be asked to provide evidence about a contradictory theory (students are not told that the theories oppose each other), and then results presented to the class.

Teaching a greater awareness of the statistical uncertainty of data collection

Fairbrother and Hackling (1997) propose alternatives to chasing a commonly known right answer during science practicals, stating the hothouse conditions related with assessed coursework can only promote improper behaviours. They conclude that pupils should not be chasing a right answer, and anomalous data should not be called wrong, but *uncertain,* due to the inherent randomness of unreliable measurement. If pupils view science results as a right/wrong dichotomy, erroneous results giving rise to a wrong conclusion are viewed as their fault and something to be corrected, whereas it may be due to chance fluctuations of the system. Citing uncertainty means it will not be seen as their error, and being uncertain in drawing conclusions may be an alien idea to students, but is scientifically acceptable. Gunstone (1991) similarly prescribes a greater awareness of the natural statistical uncertainty of data collection, which will help learners appreciate that sometimes an apparent 'wrong answer' is produced and further positive observations will reduce the significance of these aberrations. However, allowing pupils the choice to selectively label and reject anomalous, unwanted data might result in an attitude of measurements being viewed as judgements and the replacing of observations with opinions, a prime ERO-related behaviour. The authors also value open-ended investigations where the right answer is not obvious at the outset, thus setting a context for authentic enquiry, although expectations *would* form as the process progressed, and the pluralist approach accompanied by the reduced teacher-supervision associated with such investigations would increase EROs (Author, 2006) and possibly misconceptions (Kirschner, 1992).

Contrastingly, Nott and Smith (1995) conclude that espousing at all costs the idea of a positivistic right answer is a necessary evil in order to confirm accepted scientific views and challenge misconceptions. But such a position would only serve to enhance the five ERO-related problems cited above, albeit pupils would ERO in line with the scientific theory.

Rediscovering discovery

As long as positivist practical illustrations of scientific theory confirmation continue in schools, so will pupils' negations of anomalous data along with other ERO-related pursuits. Despite these problems we cannot reject wholly this useful approach. Presenting practical work as enquiry-based, open investigations may not give pupils a textbook right answer to adhere to, and there are some data to suggest that ERO behaviours would be less (Rigano and Richie, 1995). As stated, Fairbrother and Hackling (1997) say investigations place less emphasis on getting the right answer and more on the science processes involved in getting *an* answer. Indeed, it appears that with other, more closed practical tasks a drive to get the right answer, especially when linked to gaining vital marks during assessed work, is inevitable. Findings from the Author's ERO study (2006) bring an awareness of the advantages of discovery-based practical work as an alternative to confirmatory activities where a universally known right answer is chased. These constructivist-provisionalist *pseudo-discovery* lessons start with only the teacher being aware of a little-known right answer and learners are invited to uncover this secret by experimentation, and involve empirically testing a series of given hypotheses. A routine process where a well-known textbook result is churned out is avoided, and although affinity to theory does occur, there is an air of insecurity about whether a student's chosen theory is actually the right answer, especially when the concepts involve common misconceptions where the scientific view is not universally accepted by learners. No marks are lost for aligning oneself with the wrong theory, and the knowledge of no potential loss of real academic status encourages pluralism in the classroom, representing a retreat from naïve-realist absolutist views of theory. Pseudo-discovery allows a return towards a genuine spirit of enquiry for pupils, as did the Nuffield 'scientist for a day' experiments, which pupils find engaging despite the fact they have to play a game where what they 'discover' is known by the teacher, having been previously constructed by scientists and given the status of a currently acknowledged 'right answer'.

Overt encouragement of an authentic view of the nature of science

Recent revisions of the KS4 (14-16 years) science curriculum in England re-emphasises the nature of science under the umbrella of the *How Science Works* strand (QCA, 2006), with aspects of contemporary constructivist scientific methods being mirrored in GCSE examination board specifications, including pluralism, uncertainty, the statistical variability of data and the refutation of pure, unbiased, inductive observation. Perusing the specifications of one board as an exemplar (AQA, 2006), one finds statements that clearly imply a post-positivist view of science.

> "We are still finding out about things and developing our scientific knowledge. There are some questions that we cannot answer, maybe because we do not have enough reliable and valid evidence. For example, it is generally accepted that the extra carbon dioxide in the air (from burning fossil fuels) is linked to global warming, but some scientists think there is not sufficient evidence and that there are other factors involved" (ibid., p31).

These measures represent a step in the right direction and should have some influence on how practical work is delivered by addressing and reducing a number of ERO behaviours, and conceivably moving both pupils and teachers away from familiar naïve realism. That said, despite this new promotion of a post-positivist science, the presentation of substantive content as set out in the same document (ibid.) remains both linguistically and notionally a secure positivistic canon of right answers to be transmitted by teachers and digested by pupils,

> "A body of content has been identified which underpins the knowledge and understanding of How Science Works at all levels" (ibid., p12)…[An aim of the course is for pupils to] acquire and apply skills, knowledge and understanding…" (p16).

No matter how far post-positivistic influences permeate into the teaching of science content it seems unlikely that a view of the necessary status of absolute right answers will be replaced, with the familiar mixed epistemological messages being repeated by the new generation of syllabus writers. The desire to integrate *How Science Works* with substantive content is repeatedly stated throughout the AQA specifications, though the real extent to which teachers will present scientific facts as tentative entities to pupils remains to be seen – in all likelihood such an untried approach will be largely rejected, initially at least, in favour of the usefulness of the familiar transmission methods that have been shown to be successful in getting pupils through examinations.

The partial promotion of post-positivism in *How Science Works* is opposed by external cultural factors that are likely to play a significant role, as a predominant naïve-realist epistemology is reflected in the common media presentation of a positivistic interplay between scientific theory and evidence. Taking the example cited above, the tentative hypothesis of greenhouse gas build-up triggering global warming is currently offered by prime-time TV news programme makers as an absolute, with dissenters of the theory ridiculed as being irrational or having hidden agendas.

Although not expressed explicitly, it may have been the intention of the GCSE specification authors for all substantive content to be presented pluralistically as a tentative set of theories/facts to which valid alternatives exist. The delivery of such an authentic view of the nature of science to pupils was expounded by a sample of practising *scientists* during Osborne *et al.*'s (2001) survey, one of who cited provisionalism as ' "a very important concept" (So5)' (p59); also, that science does not currently hold all the answers was seen as motivating for pupils considering a scientific career. However, a minority held reservations about making known to pupils the view of theoretical tentativeness, as specialist knowledge was required to appreciate that there might be doubt about scientific theories. This rings true, as since good reasoning faculties are probably required to assimilate the authentic though pluralistic sections of *How Science Works*, these ideas could be lost on the less able, which would only swell the ranks of disenchanted teenagers who find science 'too difficult'. As argued earlier in the current article, offering science concepts as provisional entities may induce free choice when considering alternatives to long-established scientific hypotheses, leading to a simplistic, relativistic, radical-constructivist view of science as solipsism, and potentially result in for instance our pupils becoming fervent flat-earthers. The current attacks on evolution theory by proponents of Intelligent Design attempt to extend pluralism towards a relativistic extreme where all points of view have equal weighting, and pupils holding underdeveloped models of a solipsist nature of science would be susceptible to these arguments.

In response to a statement presented by Osborne *et al*. (2001) which reflected an epistemologically dualist curriculum, one scientist echoed the dilemma expressed in the current article.

> " 'At one level [the statement] requires the child *not* to question school science; at another to view 'frontier' science as *not* beyond question. Where does the boundary lie between those two types of science?" (PS05)' (ibid., p60).

Despite these difficulties, the promotion of an authentic post-positivist approach to science seems the most efficacious way to resolve the current epistemological clash, with the ideal being all pupils assimilate a sophisticated view of science that reflects contemporary constructivist philosophy. It has been realised for some time that historical illustrations of interplay between theory and evidence might help pupils construct appropriate views of pluralistic science (Fisher and Lipson, 1986), having been integrated for a number of years into an *Ideas and Evidence* strand in the science KS3 (ages 11—14) curriculum – the acceptance of a conventional pluralistic view would help bolster the defences against pseudo-scientific attacks such as those from adherents of Intelligent Design – paradoxically, the successful teaching of pluralism would counter the problems of potential solipsism noted previously that are associated with exposing pupils to post-positivistic science. Further research is necessary to determine the comparable effects of exposure to a curriculum based on a constructivist-realist epistemology, particularly with respect to performance in examinations that test learning of a substantive canon of right answers.

SUMMARY

Current curricula may present a confused view of the nature of science to pupils. On the one hand, theories are viewed as absolute truths to be learned as an examinable canon of facts; on the other, practical activities may be carried out in a spirit of genuine enquiry, where pupils collect data and judge hypotheses pluralistically towards an unknown end point. These two approaches are epistemologically conflicting, instilling a sense within pupils of the 'difficulty' of science.

Pupils adopt a positivist epistemological position when conducting many science practical activities, chasing an irrefutable right answer, and scientifically acceptable theories need to be viewed as sacrosanct in the school laboratory with the aim of many activities being the confirmation of these. However, pupil knowledge of a right answer leads to ERO behaviours in order to produce that answer, and may have further, cognitive repercussions; despite this some authors recommend data manipulations that ensure the right answer is inferred.

There are some ways in which to limit the problems relating to epistemological clash and positivistic experimenting. Discouragement of a neglectful rejection of anomalous data and reinforcing the uncertainty of the statistical nature of data collection should reduce ERO behaviours. Presenting practical work as a pseudo-discovery task, where only the teacher is initially aware of the right answer may be an appropriate compromise due to utilisation of positivistic right answer endorsement, but presentation to participants as a provisionalist task. The most holistic and effective approach would involve pupil assimilation of a fully integrated, authentic post-positivist view of the nature of science; however, currently this seems beyond the capability of science education.

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Laboratory Education in New Zealand

Thomas Borrmann

Victoria University of Wellington, Wellington, NEW ZEALAND

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Laboratory work is one of the main forms of teaching used in chemistry, physics, biology and medicine. For many years researchers and teachers have argued in favor or against this form of education. Student opinion could be a valuable tool for teachers to demonstrate the validity of such expensive and work intensive forms of education as laboratory work. However, due to concerns regarding overly positive replies and a strong personal bias in opinions regarding various courses, teachers and technicians, student opinion has largely been discounted so far. A set of markers based on the strategic aims of Victoria University of Wellington, New Zealand, have been selected and used to collect student opinion. The markers appear to be independent and present a more objective view of the value of student opinion regarding laboratory education. In contrast, direct questions showed exactly the positive bias criticized by researchers and academics. The markers based on strategic aims revealed that laboratories are valued but that certain areas of this form of education require improvement. The trends collected by use of the markers were line with replies to free-form questions and could therefore present a valid option for researchers to evaluate the effectiveness of various forms of education based on the opinions of the people most concerned, the students.

Laboratory education; Strategic Aims, Students' Opinions, Survey Validity

INTRODUCTION

Laboratory work is one of the main forms of teaching used in chemistry, physics, biology and medicine. Studies carried out in the seventies and eighties showed that students did not enjoy laboratory work (Beard and Hartley, 1984; Bliss and Ogborn, 1977, Boud, Dunn, & Hegarty, 1986; Hegarty, 1984), which came as no surprise looking at the effort (workload, commitment) and risks (chemical burns, poisoning) associated with it (chemical burns, poisoning etc.). Since then safety technology has been improved to a point where laboratory work is safe and in principle, enjoyable. But the technology improving laboratory conditions brought a significant increase in costs and effort to equip and maintain practical work areas, raising financial questions regarding their necessity and viability. New Zealand's tertiary education budget is above average for Organization for Economic Co-operation and Development (OECD) countries with 1.7% compared to 1.4% of the Gross Domestic Product (GDP) (examples: Ireland 1.3%, Finland and Sweden 1.7% and Australia 1.5%) to address continuing skills shortages (LaRocque, 2007). The GDP of New Zealand is approximately three quarters of that of other OECD countries (for example Finland and Ireland) meaning that the actual amount of funding available for tertiary education is comparatively low. Furthermore, the market-driven nature of New Zealand universities and educational institutions places limitations on the willingness of financers and managers to approve comparatively costly forms of education (Kelsey, 1998).

Doubts about education in laboratory environments are not limited to managers and financiers; teachers, lecturers and students have discovered new technologies, which can be applied in teaching at a fraction of the costs and effort of laboratory education (Bodner, 2001; Grosso, 1995; Walton, 2002; Willet,

Correspondence to: Thomas Borrmann, School of Chemical and Physical Sciences and the MacDiarmid Institute for Advanced Materials and Nanotechnology, Laby Building, Room 402, Victoria University of Wellington, P.O.Box 600, 6140 Wellington, New Zealand
E-mail: thomas.borrmann@vuw.ac.nz

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2006). The discussion about laboratories and other educational techniques is very opinionated, with many scientists arguing heatedly either in favour (Blosser, 1990; Bond–Robinson, 2005; DeMeo, 2001; DiBase and Wagner, 2001; Hofstein, 2004; Johnstone and Al-Shuaili, 2001; Kampourakis and Tsaparlis, 2003; Lloyd, 1992; Stanholtzner, 2002; Stanholtzner, 2003) or against (Balla, 1990; Hawkes, 2004) laboratory education. Recently, the online journal Chemistry Education Research and Practice (2007) dedicated a special issue to articles about "Experiments and the Laboratory in Chemistry Education". Several articles in this edition of the journal discuss the history, development and current standard in laboratory education.

One question is often ignored in this context: What do students think about laboratory education? In 2006 John Steven Polles wrote a PhD thesis investigating the student perspective on chemistry teaching laboratories. Polles (2006) found that students' experiences were strongly dependent on their learning environment and the stance of their teachers, lecturers, demonstrators and technicians. This dependence raises questions regarding the validity of assessing student opinion. Many academics feel that students tend to give overly positive replies that do not reflect their true opinions regarding different forms of education, if asked directly. However, if independent and indirect instead of direct questions are used, where, for example, students comment on the realization of certain aims and goals instead of commenting on the matter in question directly, a more objective and useful opinion poll might be collected. A comparison of the direct and indirect method of questioning, for example in a survey, should show a difference in the distribution of opinions depending on the method of questioning. It is postulated that asking students about the realization of aims and goals in a course should yield a wider spread of replies overall and clear differences in the opinions regarding various goals and markers. This is in contrast to direct questioning, which yields positive but dubious results as expressed in a lack of spread between replies to different questions. Therefore, the validity of an indirect approach for collecting students' opinions can be shown by an investigation of the statistical distribution of replies. Should the distribution yield a believable spread and prove questions to be independent, students' opinions might be considered more valuable and useful in deciding on the quality and usefulness of different forms of chemistry education.

Case Study - An Investigation of Students' Opinions Regarding Chemistry Laboratory Education

As a case study an investigation of students' opinions regarding chemistry laboratory education was chosen. The reasons for this choice were the familiarity of the investigator with the subject area and the clarity of the aims and goals formulated. Based on statements from the strategic plan of Victoria University of Wellington, New Zealand, and conversations with the Dean of Science, with lecturers in chemistry and the Head of the School of Chemical and Physical Sciences a list of the seven most important joint strategic goals for the University and the School was collated. The goals are directly linked to generic, course-independent attributes, which a chemistry student at Victoria University should have or attain during study. The list was limited to seven items based on the weighting attributed to the individual goals in the discussions. Between the selected seven items and other items not included in this study a perceivable step in weighting was noticed. According to University and School guidelines the goals assessed in this study should be realized in the teaching curriculum, for examples in the university calendar, course outlines and reports.

The seven attributes thought to be the seven most important (in no particular order) are:

i. Confidence
ii. Interest
iii. Linking theory with observation
iv. Critical thinking
v. Scientific methods like analysis, observation and the deduction of results based on observations
vi. Leadership skills
vii. Practical skills

A questionnaire was formulated and distributed in chemistry lectures and laboratories of all levels in the last week of the second trimester in 2006. Ethical standards were strictly obeyed in the collection and handling of the questionnaire, a copy of which is available as appendix. Early in the planning of the presented study the need for strict limits was noticed. These limits were set in order to minimize disruptions to the students' curriculum and were realized by focusing on seven strategic goals perceived as most important by the University and School (listed above). Furthermore, the study was limited in terms of the data collection method applied – meaning that the only method of collecting data used in this study was a questionnaire. A small follow-up study was carried out mid 2007 to elucidate the effect of level on the results obtained. Further follow-up studies should investigate the same set of goals using other techniques, for example interviews of focus groups, to ensure the validity of the results presented here.

The questionnaire was structured into four blocks, the first being used to accumulate demographic information about the students participating (enrolment in lectures, enrolment in laboratory courses, number of laboratory courses participated in, involvement in research projects, gender, origin, and status – 1st Year,

Table 1. Return rate

Level	Students Enrolled, No.	Questionnaires Distributed, No. (Percentage)	Questionnaires Returned, No. (Percentage)	Return Rate - Returned Questionnaires/Enrolled Students (Percentage)
100	189	147 (77.8%)	107 (72.8%)	0.566 (56.6%)
200	72	67 (93.1%)	62 (92.5%)	0.861 (86.1%)
300	24	22 (91.7%)	18 (81.8%)	0.750 (75.0%)
All	285	236 (82.8%)	187 (79.2%)	0.656 (65.6%)

Table 2. Statistics from direct questions asked regarding the value of laboratory education

	General Understanding	Understanding Key Concepts	Time and Effort	Achievements and Progress
Median	3.7123	3.5189	3.4764	3.4811
Mean	4.0000	3.5000	3.2500	4.0000
Std Dev	1.0023	0.8421	0.9471	0.9282
Std Err	0.0973	0.0818	0.0920	0.0902
95% Conf	0.1930	0.1622	0.1824	0.1788
90% Conf	0.2554	0.2146	0.2414	0.2365
Size	106	106	106	106
Total	393.5	373	368.5	369
Min	1.0	1.0	1.0	1.0
Max	5.0	5.0	5.0	5.0
Min Pos	1.0	1.0	1.0	1.0

2nd Year etc.). The second block contained four direct questions regarding the general value of laboratory education, (1) evaluating how laboratories contribute to the general understanding of chemistry, (2) the understanding of key concepts, (3) the value of practical education in respect to time and effort spent and (4) the achievements and progress in chemistry. The third block (the indirect part) asked how far the strategic aims listed above are realized in Victoria University chemistry laboratory courses. The last block contained four free-form questions, asking for feedback on the positive and negative aspects of laboratory education, suggestions for improvements and general comments.

Answers to the questions were categorical to avoid confusion, with five categories given – the positive always being on the left and the negative always being on the right hand side (see appendix). Students were told that they could choose two categories to express that their answer lies between the categories given. This means that a total of nine categorical answers were possible for each question. For the evaluation of the student's answers, the five main categories and four intermediates were translated into a 9-point scale of numbers, '5' standing for most positive and '1' for most negative possible. The step width was 0.5 (meaning answers could have the following values: 5.0, 4.5, 4.0, 3.5, 3.0, 2.5, 2.0, 1.5, 1.0). After compilation of statistical data (calculation of means, errors, chi-tests etc.) and construction of box plots the numbers were transformed back into categories for interpretation of the results calculated.

Return Rate

One of the issues facing any study is that of return rate: Is the sample group participating in a study representative of the student population? In this study it was decided to choose all enrolled chemistry students as population. As no sampling was undertaken the study should be representative of the opinions of all chemistry students at Victoria University. It was further decided to carry out a survey close to the end of a trimester. This choice of time means that students are pre-occupied with exams, assignments and presentations and attendance levels and response rates to questionnaires can be low. This is offset by the higher level of experience the students have accumulated. As experience of laboratory teaching is important for the purposes of this study, a lower response rate was accepted as a risk. As expected attendance levels had dropped (Table 1). However, even an attendance of 77.8%, as on the 100-level (1st year students), is respectable. Therefore, a return rate of 72.8% means that 56.6% of all 100-level students enrolled in chemistry participated in this study, which means that it can be considered representative. The values for 200-level (2nd year students) and 300-level (3rd year students) are even better, 86.1% and 75.0% respectively. This means that a total of 65.6% of all undergraduate

Table 3a. Realization of strategic aims in laboratory education; Part 1

	Confidence	Interest	Linking Theory with Observation
Median	3.4764	3.4387	3.5896
Mean	4.0000	4.0000	4.0000
Std Dev	0.9370	1.0904	0.9631
Std Err	0.0910	0.1059	0.0935
95% Conf	0.1805	0.2100	0.1855
90% Conf	0.2388	0.2779	0.2454
Size	106	106	106
Total	368.5	364.5	380.5
Min	1.0	1.0	1.0
Max	5.0	5.0	5.0
Min Pos	1.0	1.0	1.0

Table 3b. Realization of strategic aims in laboratory education; Part 2

	Critical Thinking	Scientific Method	Leadership	Practical Skills
Median	3.1132	3.8113	2.2311	3.9292
Mean	3.0000	4.0000	2.0000	4.0000
Std Dev	0.8654	0.8178	0.9836	0.8603
Std Err	0.0841	0.0794	0.0955	0.0836
95% Conf	0.1667	0.1575	0.1894	0.1657
90% Conf	0.2205	0.2084	0.2507	0.2192
Size	106	106	106	106
Total	330	404	236.5	416.5
Min	1.0	1.0	1.0	1.0
Max	5.0	5.0	5.0	5.0
Min Pos	1.0	1.0	1.0	1.0

Table 4. Comparison of average medians, spread of medians and maximum standard error for years 1-3

Year	1st		2nd		3rd	
Questions	Direct	Indirect	Direct	Indirect	Direct	Indirect
Average Median	3.55	3.36	3.74	3.61	4.18	3.95
Spread of Median	± 0.09	± 0.52	± 0.12	± 0.51	± 0.23	± 0.49
Max Std Err	0.10	0.11	0.12	0.13	0.22	0.25

students enrolled in chemistry at Victoria University participated in this study. It is possible but not expected that the opinions of these students differ significantly from the opinions of all chemistry students.

Comparison of Results – Direct Questions versus Indirect Indicators (Strategic Aims)

Looking at the replies for the first year students, the distribution of medians for the direct questions regarding the value of laboratory education is 3.55 ± 0.09. This spread of results is well within the standard error of each of the four individual results (Table 2). The consistency of replies raises serious doubts regarding their value. It is quite possible that the positive aspect of the replies is overstated and approval for laboratory education solely based on these results would be over-estimated. A graphical interpretation of the spread of results between the different questions can be found in Figure 1. The size of the spheres is equivalent to the number of replies. Table 3a and b show that the distribution of medians for the indirect questions regarding the realization of strategic aims in laboratory education is far less uniform. The average of the medians shows a far larger spread with a value of 3.4 ± 0.5. The standard errors for the individual strategic aims are of the same order and magnitude as those for the direct questions. This indicates that the results in themselves for the indirect questions are as consistent as the direct questions, but the spread of the means is five times as large compared to the standard errors, indicating that the variables assessed are independent

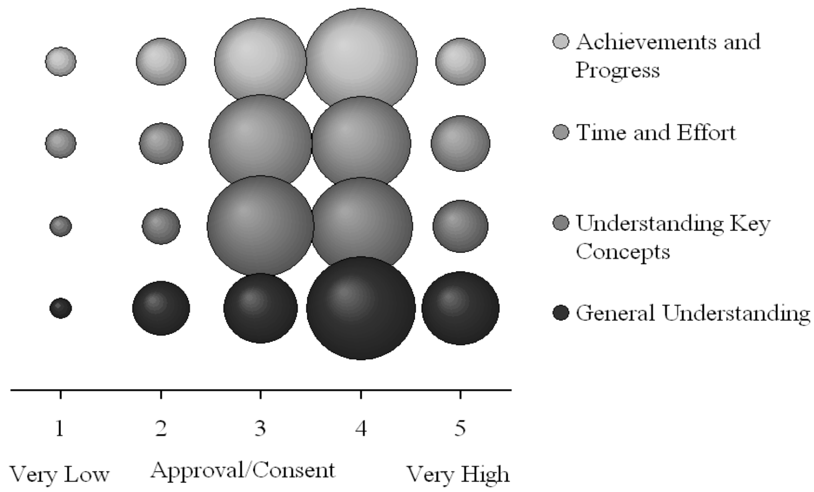

Figure 1. A bubble plot showing the distribution of answers to the direct questions regarding the value of laboratory education

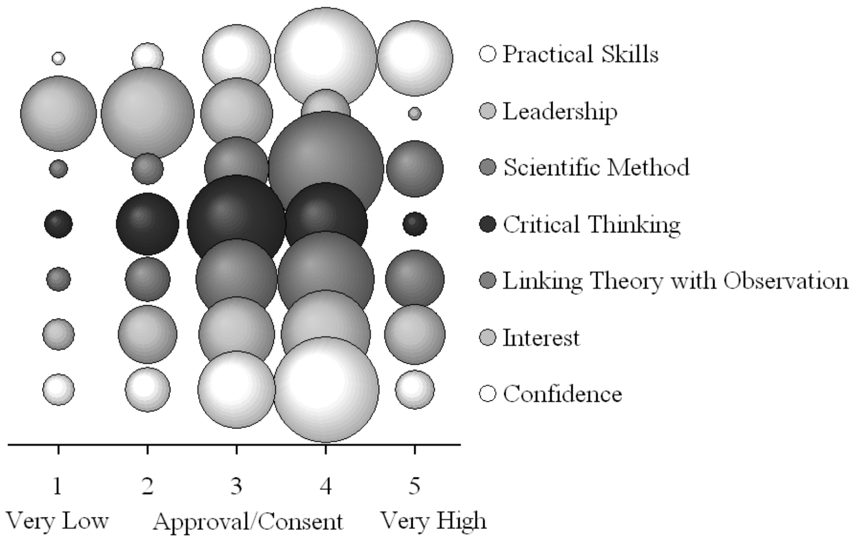

Figure 2. A bubble plot showing the distribution of answers to the indirect questions regarding the realization of strategic aims in laboratory education

and probably closer related to the real opinions of the students. The question regarding leadership even yielded a response slightly below medium. A graphical representation of the spread of results between the different strategic aims is shown in Figure 2. The size of the spheres is equivalent to the number of replies.

Results for years 2 and 3 show similar statistics but as the sample size decreases the standard errors increase, while the spread of results remains similar. A comparison distinguishing between direct and indirect questions of the standard errors (maxima only), average medians and their spread for the years 1 to 3 is presented in Table 4. In principle the postulation appears to be true that using indirect questions gives a wider spread of results than the more direct approach. It appears that the results from the direct questions indeed over-estimated the positive nature of students' opinions and were of limited usefulness to assess the value of laboratory education. In return this indicates that the indirect method has some degree of validity and that the strategic aims chosen, as indicators are useful assessment tools.

Interpretation of Results from the Direct Questions Regarding the Value of Laboratory Education

In general the attitude towards laboratory education is positive. The medians for all answers are in the range between average and positive (Table 2). The interquartile range as calculated from the probability density function is nearly always within one main category; the only exception is the question regarding the contribution of laboratories to the general understanding of chemistry. All observations are within two to three main categories, meaning that the opinions are very consistent for all students participating. While answers were received in all five main and four intermediate categories, the most negative opinions were only present as outliers, meaning that answers in them are located more than one main and one intermediate category outside of the interquartile range. Less than 1% of all students have a negative or very negative opinion about laboratory education.

This is illustrated in Figure 3, a box plot created according to guidelines by Tukey and Iglewicz (1989). In light of the study carried out by Polles (2006), this could mean that the learning environment in the laboratories was supportive and positive, credit to the chemistry staff of Victoria University. However, as the statistical analysis of the results indicates that results might be overly positive, care must be taken in the interpretation of these findings. As before the plot in Figure 3 was constructed from the surveys collected from 1st year students as the larger numbers gave an adequate frequency of responses (Figure 4). While the margin of error increased, the distributions for 2nd year and 3rd year students compared to 1st year and for students from all years, the histograms appear to follow approximately the same shape, which indicates that results are valid and can be used for modelling replies and constructing box plots.

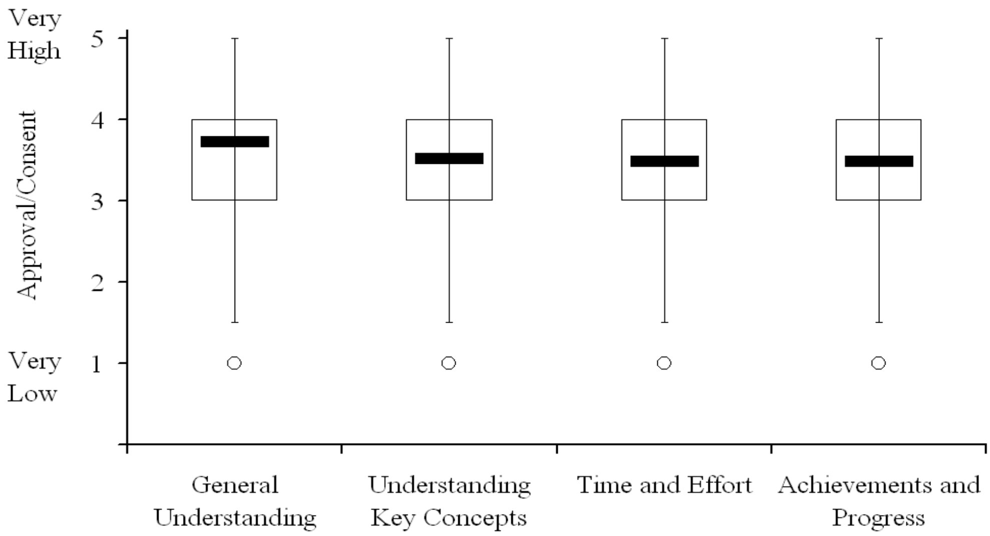

Figure 3. Box plot showing the spread of opinions of 1st year students regarding laboratory education assessed by direct questions

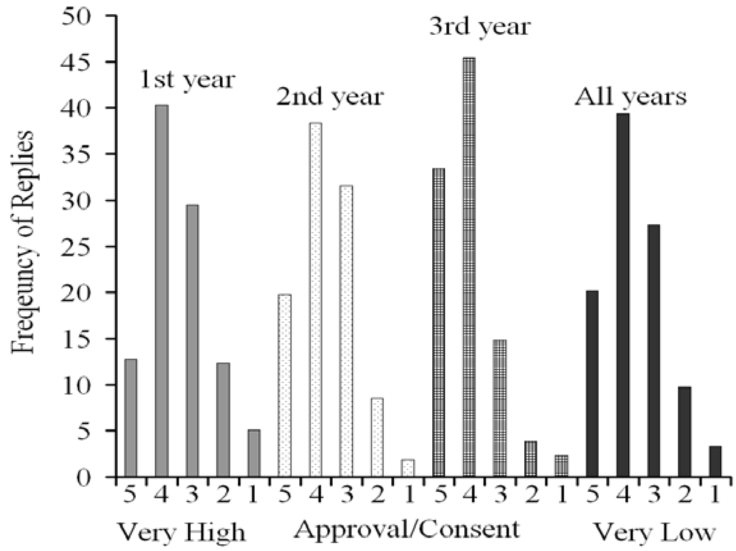

Figure 4. Histogram showing the frequency of replies in each approval category:
1 = very low, 2 = low, 3 = average, 4 = high, 5 = very high

Opinions Regarding the Realization of Strategic Aim

Results in terms of the strategic aims are more diverse (Figure 5). Aims in regards to confidence, interest, linking theory with observation, and scientific method have been achieved well, with replies being between neutral and positive. Critical thinking is not realized as well, with opinions tending more towards a neutral position. It is likely that due to a relatively narrow knowledge, undergraduate students have not yet had sufficient opportunity to train themselves in the evaluation and discussion of concepts. Pending findings among the postgraduate students, this might be an issue that should be discussed amongst and remedied by the academic staff and students. Leadership was the only strategic aim not fully realized in chemistry laboratories. The undergraduate laboratories leave little room for the students to take leadership roles. Owing to safety considerations, instructions, guidelines and requirements are precise and strict, especially for 100-level students, allowing little room for taking leading roles. Only on 300-level do students start to embark on self-guided independent research. Whether this independence is reflected in their tendency towards this strategic aim will be discussed below. One other strategic aim is prominent – practical skills, which due to the nature of laboratory courses is not surprising. Opinions regarding the acquisition of these skills are positive to very positive with the median lying above the positive category.

Several researchers have investigated the relation between laboratory work, lectures and other teaching techniques (Bodner, 2001; Grosso, 1995; Walton, 2002; Willet, 2006). DiBase (2002) and Polles (2006) both came to the conclusion that a good alignment between

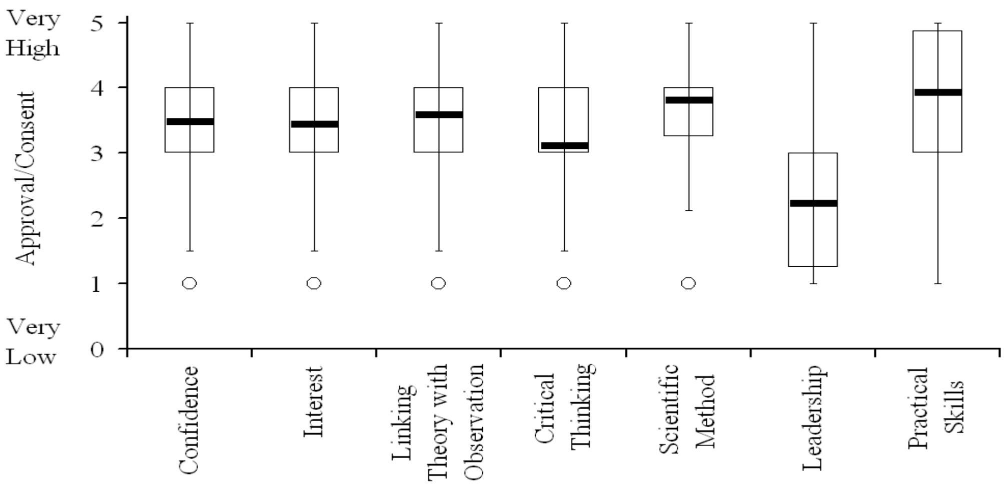

Figure 5. Box plot showing the spread of opinions of 1st year students regarding laboratory education assessed by indirect questions. Students were asked to judge the degree at which strategic aims were realised in laboratory education

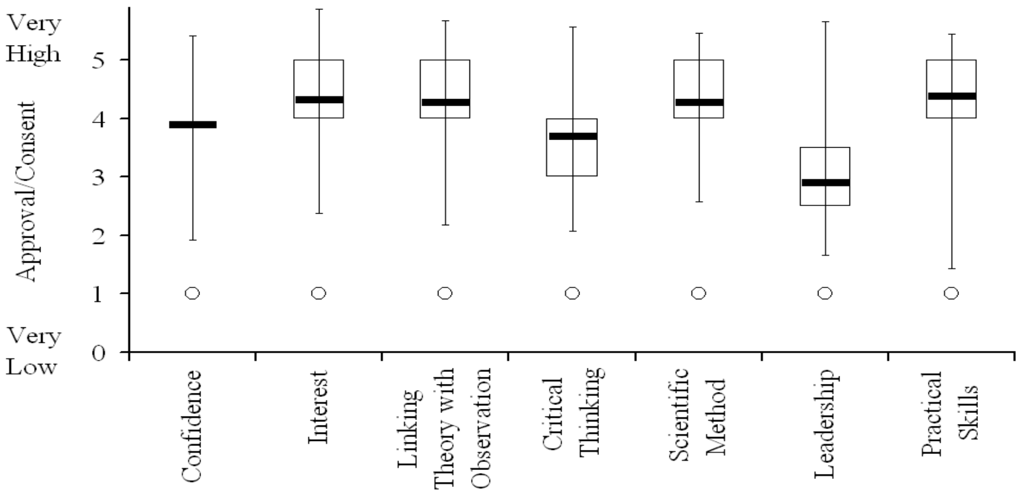

Figure 6. Box plot showing the spread of opinions of 3rd year students regarding laboratory education assessed by indirect questions

the different forms of teaching needs to be achieved for maximum effectiveness. DiBase (2002) and Deters (2005) have both suggested strategies for how this may be achieved. The effectiveness of the link between the different teaching techniques, lectures and laboratories, at Victoria University was documented in the corresponding question (see Figure 5. Linking theory and observation) and in the free-form part of the questionnaires, where 31.3% of the students stated that laboratories helped them understand concepts and how they relate to observations and findings, something which is difficult to achieve, if the students are only presented with data and do not carry out the experiments. Further positive points mentioned by approximately a quarter of the students were visual learning (22.9%) and the acquisition of practical skills (27.7%). Negative remarks – only comments about the high workload and time required were stated by a significant amount of students (28.2%). Only 33.2% of all participating students used the free-form questions.

The raw data has been submitted to Chi-square tests to see if group (other than level) specific trends would be noticeable by correlation of the replies to the questions with demographic data also collected in the questionnaire. The result was overwhelmingly negative, with the error in the Chi-square test being unacceptably high (22%), which means that no statistical significance for differences between any of the demographical groups has been observed.

While the spread of results includes negative as well as positive opinions, the overall trend is quite positive, with students' opinions being quite favourable towards laboratory education.

The Development of Opinion through the Levels

Student opinions, regarding the alignment of laboratory education and strategic aims, improve as students advance through the levels. While there is a noticeable improvement in opinion between 100-level and 200-level, the opinions expressed by 300-level students are very positive (Figure 6). Victoria University has a policy of research-led teaching in line with good teaching practice as formulated by Vallarino, Polo, & Esperdy (2001). At 300-level the students become involved in independent three-week research projects. Nearly all opinions are in the range between positive and very positive. Only the opinions regarding the realization of critical thinking and leadership in laboratory education are still lower than the rest, but even they are significantly improved, with critical thinking tending towards a positive rating and the opinions regarding leadership being expressed relatively evenly around the neutral mark.

Seeing the improvement in opinions as the students advance through the levels, one question remains: Did student opinion improve or did the students with negative and neutral opinions move to other subject areas? This question was answered in a short follow-up study that showed that over 95% of the students' opinions improved as they progressed through the levels. The follow-up study included students moving to other subject areas; of the seventy-two 200-level students surveyed initially 52 (72.2%) were included and replied to the follow-up study. Of these 52 students 38 were still pursuing a chemistry degree at Victoria University. The students commented that this improvement in opinion is due to better linkages between lectures and laboratories at 300-level than at the lower levels.

CONCLUSION

The presented study yielded two results. First, responses from asking students directly to assess the value of laboratory education were compared to questions where students assessed the realisation of strategic aims in Victoria University of Wellington laboratory courses. It was shown that the direct questions over-estimate the approval of students for the form of education they are undergoing. The strategic aims appeared to act as independent indicators giving a far more realistic picture of student opinion. The second result from this study is the finding that even the indirect questions yielded a positive result. Students appear to value laboratory education highly and as they progress through the levels and the linkages between lecture and laboratory materials increases the appreciation of students for laboratory education grows as well. Several strategic aims, especially those regarding confidence, interest, linking theory with observation, scientific method and practical skills have been achieved quite well, with replies ranging between neutral and positive. Critical thinking and leadership are not realised well and laboratory personnel and academics should consider how to improve laboratory education in this regard. Lectures and other forms of teaching and learning usually achieve better results in regards to critical thinking, but fall short in terms of inspiring confidence, interest, and linking theory with observation. In light of the achievements of laboratory education, and the way it compliments other forms of education, it remains important to keep it despite the (sometimes) high costs involved. Student opinion certainly appears to places a value on it, and teachers and academics are wise to consider the opinions of their students.

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The Effect of Using Graphing Calculators in Complex Function Graphs

Mehmet Akif Ocak
Gazi Üniversitesi, Ankara, TURKEY

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This study investigates the role of graphing calculators in multiple representations for knowledge transfer and the omission of oversimplification in complex function graphs. The main aim is to examine whether graphing calculators were used efficiently to see different cases and multiple perspectives among complex function graphs, or whether graphing calculators were used only as a mechanical tool to push buttons and execute memorized steps. Twenty individuals chosen from seven college calculus I classes (148 students) participated in this study. A survey was administered to students in order to find their attitudes and prior use of using graphing calculators. Data was gathered from the video-taped interviews with students to determine how the graphing calculator was used in the tasks and to get a deeper understanding of college students' engagement process with graphing calculators. The results indicated that experience with the graphing calculator was important factor in solving the tasks with the graphing calculator, while attitude seemed to have no effect on task solving steps. Results clearly show that in order to use the graphing calculator in complex function graphs to implement the multiple representations of knowledge, the students need to know characteristics of features on the graphing calculator. They have to have some use of skills and good experience on the machine, not just skills of thinking and skills of knowing the concept.

Keywords: Complex, Function, Graph, Attitude, Experience, Calculator.

THE EFFECT OF USING GRAPHING CALCULATORS IN COMPLEX FUNCTION GRAPHS

The use of graphing calculators is becoming common in mathematics classes. However, little is known about why and how graphing calculators make a difference in mathematical understanding. There are two reasons for that. First, much of the initial research on graphing calculators only compared the achievement and attitudes of different student groups using graphing calculators and traditional instruction (non-calculator groups). Secondly, research generally looked at students' basic mathematical ability with very minimal graphing calculator utilization. What is missing from research on the use of graphing calculators is important information about the role the graphing calculators play in the class environment. The students' flexibility on understanding of graphical concepts was mostly ignored.

Hennessy et al. (2001) showed both that graphing calculators can be used mechanically, and manual/paper-pencil work to show the steps of drawing the graphs on the paper is essential for students to develop concepts and skills in a difficult curriculum area. In their survey results, it seemed clear that despite positive immediate feedback, rapid and easy plotting, and visualization with graphing calculators, most students struggled with understanding mathematical concepts. This indicated to authors that some manual (paper-pencil) work and tutor help was needed. Graphing calculators saved both time and space, but Hennessy et al. (2001) concluded that both graphing activities and examinations need some kind of

Correspondence to: Mehmet Akif Ocak, Assistant Professor of Instructional Technology, Gazi Üniversitesi, Gazi Egitim Fakultesi, BOTE Bolumu, L- Blok, 304 Teknikokullar, Ankara, 06500, TURKIYE
E-mail: maocak@gazi.edu.tr

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conceptual understanding rather than the sole use of graphing calculators.

Graphing calculators give students automatically produced graphs. By using real data, students can get immediate feedback from the graphing calculators, compare and contrast different graphical representations simultaneously. In this way, with immediate input and output, students can improve their own explorations by using the features of graphing calculators. However, it is also possible that graphing calculators might cause automatized procedures (key pressing steps or memorizing to push buttons) rather than enhance students' understanding of complex graphical concepts. Automatized procedures might affect students' understanding of graphical concepts. Using graphing calculators might cause students to memorize key stroking steps (and only produce answers) for graphical tasks, without understanding the drawing steps of graphs.

Some researchers expressed their concern about the use of graphing calculators as a mechanical process (e.g., memorization of key pressing steps). They stated that this process might lead students to avoid the process of drawing a graph and turn their attention to only the graph itself (Yerushalmy & Schwarts, 1993; Hennessy et al., 2001). Even with the easy plotting with graphing calculators, students may not get beneficial ideas from the multiple representations of functions. Doerr & Zangor (2000) found that students saw graphing calculators as a "black box" and they only used it as a private tool. In their study, as a private tool, students showed frequent failure to join group discussions while using graphing calculators. Moreover, students did not show a meaningful strategy for the use of the graphing calculators. They failed to produce meaningful interpretations of the task situation with the graphing calculator.

Kwon (2002) focused on students' graphing ability in terms of interpreting, modeling, and transforming, and indicated that calculator-based range activities enhanced students' ability to understand graphs. Actually, these three components (interpreting, modeling, transforming) were based on Leinhardt et al.'s (1990) action-task classification of graphing and functions. In this classification, there are two components (interpretation and construction of the graph) in action and four components (prediction, classification, translation, and scaling of graph) in tasks. When graphing calculators are used, scaling and construction processes (and partially translation) are totally lost. However, interpretation, classification, and prediction have the potential to be improved efficiently when using the features of graphing calculators for complex graphs. Literature does not say explicitly whether using graphing calculators cause students to lose some of these components. Especially, when the graphs become complex, we do not know how much graphing calculators can make positive contribution to students' graphical understanding.

Spiro et al. (1991), in their cognitive flexibility theory, gives considerable attention to complex domains in the learning process. They suggest that learners integrate different aspects of the knowledge to increase transferability to different learning contexts in order to create new representations. However, one would appreciate how it is difficult to make these transformations in the reasonable class time. It is not very clear whether using different cases and examples (with graphing calculators) in their full complexity facilitate learning in complex function graphs. Someone would expect that students will be able to classify, translate and interpret the complex function graphs flexibly. Since some studies argue that the graphing calculator can be used mechanically, it is important to see how this mechanic procedure occurs in students' use of the graphing calculator. Seemingly, using the graphing calculator might help student to see and master categorization of graphing tasks and affect their understanding in the process of constructing graphs, when the graphical tasks become complex.

There is some research on how students use graphing calculators and what kind of patterns/modes emerge (e.g., as a tool for exploratory or confirmation tool, and /or for graphical representation or numerical representation) on complex functions that have not been always examined. Hennessy et al. (2001) identified three roles of graphing calculators: a catalytic role, a facilitating role, and a checking role. However, Doerr & Zangor's (2000) description was more detailed. Through their analysis of the data, they identified five categories of patterns and modes of calculator use: computational tool, transformational tool, data collection and analysis tool, visualizing tool and checking tool. Similarly, Kwon (2002) highlighted three patterns: interpreting, modeling, transforming. From a different perspective, Choi-Koh (1999), in his case study with one student, used Bloom's taxonomy for cognitive domain in the use of graphing calculators. He identified six patterns while the student was working on graphing calculators: evaluation, synthesis, analysis, application, comprehension, and knowledge of terminology.

It can be hypothesized that graphing calculators, by using supporting material, are suitable to understanding and solving complex function graphs and helping students use different representations. Graphing calculators can provide opportunities to solve complex function graphs and by helping students explore functions and their graphs in more than one way. Heid (1988) pointed out that in calculus courses, students are mostly assigned very traditional and straightforward functions to graph such as $y= 2x^2+5x+2$ or $y=2x^2-5x-3$. Without technology, these equations also require considerable time to draw the graphs. Demana, Schoen, &Waits (1993) argue that limiting ourselves to traditional function graphs seriously restricts students from functions that they can manipulate. Students mostly solve linear and quadratic functions in both traditional high school curricula and college calculus classes. However, as Tall (1997) pointed out, traditional calculus curriculum includes mastery of symbolic methods for differentiation and integration and applying these to work with a range of functions. This position makes it necessary to approach calculus in different ways, with a consequent variety of curricula. Moreover, calculus includes a broad range of functional forms that college calculus classes do not cover as much.

Moschkovih, Schoenfeld & Arcavi (1993) argue that there are at least two ways to approach solving calculus tasks (analytic solutions and graphical solutions). The situation becomes more challenging when considering more advanced functions. Additionally, Romberg, Carpenter & Fennema (1993) argued that the creation of most graphs, especially in complex functions, like polynomial or logarithmic functions, is very difficult. The difficulty comes from the fact that many function graphs require many points to be plotted and sketched. Also, the creation of the pair values in a table is a more difficult and advanced situation. Using the graphing calculator allows students to see changes and transformations on more advanced functions and their graphs at the same time. In other words, graphing calculators allow students to see where complex graphs shift, reverse, and stretch; and allow students to see different case examples(function and their graphs) to show multiple perspectives of the content with its complexity and ill-structuredness.

Thinking about the complexity of calculus topics, one would appreciate how it is important to use multiple representations of information. An assumption underlying this study was that graphing calculators are suitable to do these multiple representations. It is vital to see which representation (graphical, numerical, or algebraic) or combination of representations students choose to use and how they use them when they solve complex function graphs with graphing calculators. Therefore, there is a need for a study to document the ways graphing calculators were used by individual students. It is necessary to look at the students while using graphing calculators to examine how they used them, when they were using them, for what kind of purposes, and whether calculator use enhanced their understanding/learning in complex function graphs.

Tall (1997) argued that a student's development of cognitive flexibility in calculus requires significant constructions and re-constructions of knowledge. He mentioned that the way in which numeric and symbolic representations develop involves an interesting form of cognitive flexibility. In his study, calculus was summarized as the study of "doing" and "undoing" the process. In this process, the flexibly in switching from one representation to another seemed very difficult for the average student. Students managed to move from one representation to another, but failed to move flexibly back and forth. Graphing calculators can be capable of providing multiple representations of many calculus tasks to help students learn to think about calculus concepts flexibly. Additionally, Boers & Jones (1993) studied students' use of graphing calculators to find the graph of

$$f(x) = \frac{x^2+2x^2-3}{2x^2+3x-5}$$

Results indicated that 80%of the students had difficulty reconciling the graph with the algebraic information. Moreover, Quesada (1994) introduced graphing calculators into a calculus class. However, 60% of the students received a grade of D or F, or withdrew from the course, which the author interpreted as students' lack of a clear understanding of the basic function graphs that they could not read basic graphs, after calculators were introduced.

Mostly, in traditional math classes, students are supposed to stick with certain types of functions. However, graphing calculators can give students a chance to see different and more complex function graphs by using different representations. Actually, the teacher, in a class environment, needs some kind of environment in which multiple representations are used efficiently to transfer knowledge, and that oversimplification must be avoided. Since most existing studies only compared the use of graphing calculators with the use of paper and pencil methods on the same kind of tasks in a very short class time, the question of how the use of graphing calculators can be used to enhance cognitive flexibility is unanswered.

This study looks at the role of graphing calculators in multiple representations for knowledge transfer and the omission of oversimplification. For example, thinking about the transfer of knowledge through the lens of literature, it is interesting to see the reactions of students to basic types of transformations (e.g., horizontal shift, vertical shift, reflection about the *x*-axis/*y*-axis/ the origin) done using graphing calculators. Thinking about the notation *y*=f (*x*), even in simple function graphs, the importance of using graphing calculators is still unknown. The idea of using multiple representations of knowledge fits well with using the graphing calculator. That is, graphing calculators are capable of providing multiple representations of mathematical concepts. Students can easily switch among tabular, algebraic, and graphical representations, allowing them to observe patterns and relations. By building tables, tracing along curves, and zooming in on critical points, students may be able to process information in a varied and meaningful way.

Purpose of the Study

By connecting the ideas from current research literature on graphing calculator, this study investigates how college students use graphing calculators to construct and understand complex function graphs in calculus. The main aim is to examine whether graphing calculators were used efficiently to see different cases and multiple perspectives among complex function graphs, or whether graphing calculators were used only as a mechanical tool to push buttons and execute memorized steps. It can be expected that allowing students to use graphing calculators will enable to look at the introduction of complex function graphs without oversimplification. Or, as some researchers argue, college students might become too dependent on the graphing calculator and lose rich and flexible understanding in calculus topics when the graphing calculator is used.

Spiro et al. (1991) and Resnick (1988) argued that most teachers heavily rely on the simplification of the topic. It is not saying that learning should begin with mass complexity, because that can lead to confusion. Theoretically, using graphing calculators can accelerate the understanding of experiences with different function graphs so students are better prepared to apply their knowledge to new or similar cases.

The literature suggests that students must build a broad knowledge base and flexibility of thought that facilitates learning in complex, non-linear functions. Therefore, it was hypothesized that graphing calculators would help students enhance their understanding of function graphs in calculus classes. Moreover, this study will examine whether students' understanding is affected by their prior knowledge of and attitudes toward graphing calculators. Following questions were addressed by this study:

1. How are the patterns students follow in constructing complex function graphs related to complexity and difficulty level of tasks when the students work with graphing calculators?
2. To what extent flexible thinking and/or rote memorization of knowledge occur when students are working with complex functions on graphing calculators?

METHOD

Participants and Setting

Twenty individuals chosen from seven college calculus I classes (148 students) in Upper New York State participated in this study. This study was conducted in at three institutions: private college, community college, state university. In order to diversify the range of students, I chose classes with differing ability of using graphing calculators. Seven classes were from a community college (one class=22 students), a private college (three classes=total 53 students), and a state university (three classes=total 73 students).

A survey was administered to students in order to find their attitudes and prior use of using graphing calculators. Attitude survey questions were based on the work of Meriwather & Tharp (1999) and Milou (1999) who used the Attitude towards Graphing Calculators (UATGC) survey for attitudes/beliefs about graphing calculator. This survey was used before and established content validity. The prior knowledge survey was a set of 8 statements that were intended to find students' prior/initial knowledge and expertise in use of graphing calculators. The survey consisted of four yes/no items, two Likert Scale items, one application question, and one qualitative question. For this survey, based on Hennessy et al. (2001) and Hubbard (1998), a Prior Knowledge with Graphing Calculators (PKGC) rating scale was developed. Two experts in mathematics education independently reviewed the instrument and indicated that, in their opinion, it had content and construct validity. The surveys were administered during the first two weeks of classes. I used mean (average) scores for the cutoff between positive attitude-negative attitude and high experience- low experience. For attitude scores (for 148 students), the average score was 55.5(minimum=37, maximum= 74). For prior experience scores, the average score was 10.9 (with a 0 minimum score and 16.5 maximum score). However, 0(zero) represented the group of the students who were unlikely to use the graphing calculator at all. Thus, the minimum non-zero prior knowledge score was 2.5, and students with a scale score of 0 were excluded.

Twenty students (from the students who agreed to be interviewed) were chosen based on four groups: positive attitude+low experience, positive attitude+high experience, negative attitude+low experience, and negative attitude+high experience. There were several reasons for the choice of these four groups. These groups were selected in accord with practical considerations. That is, based on students' prior knowledge and attitudes, these groups were crucial to goal of determining whether students' interaction with the graphing calculator was taking place and, if so, identifying the patterns of the interaction (graphing calculator use) and the practices facilitating it. Additionally, it was vital to use these groups to ensure a valid sample and how each group responded to using graphing calculators based on complexity and transferring knowledge. A total 88 students (out of 148) agreed to come to interviews. After that, I began to email students to choose 20 targeted participants (out of 88 students).

Students Interviews

Videotapes were used to record the interviews. In this way, the tape was replayed several times for analysis. Also, videotapes were used for comparisons. The video-tape only showed students' work and captured their calculator strokes. Video camera was set up and operated by researchers. Videotapes were needed to show exactly students' work and key strokes while students were using graphing calculators. In order to describe students' interactions with the graphing calculator, these interviews were vital in terms of how each student responded to certain situations on the tasks.

Targeted students were interviewed after their mid-term exams about their intentions for the use of graphing calculator, the tasks they received during the interview, and their general reactions while working on the tasks. During the first tasks, the questions were easier and shorter (low level tasks) compared to the questions in the latter tasks. There were two reasons for that. First, the goal was to minimize the pressure on students and get them more engaged with the tasks. Moreover, the goal was to try to understand student's fluency with graphing calculators and to gather information about students' familiarity with the graphing calculator. Secondly, by giving students more complex tasks in latter tasks (high level tasks), I was be able to see their proficiency in calculator use more closely. The time period ranged from 26 to 52 minutes for the interviews. The number of tasks in the interviews ranged between 4-6(no less than 4, and no more than 6) tasks depending on students' enthusiasm and on what they were capable of. As soon as the interview begins, I provided only one task to the student. When the student is done, I provided another task (Questions were given separately). I arranged tasks based on their difficulty level. All students did not receive the same sequence of tasks. Tasks were given based on the students' ability so that they were working on tasks that matched their level of expertise. Practically, it was not very possible to give the students same tasks since they had different mathematical knowledge and different tendency to use the graphing calculator. Mostly, I decided give next task while the students was working on previous one. I asked two mathematics professors(not from the study classes) independently to review and categorize each task as *low level*, *medium level*, and *high level* task based on its difficulty and complexity. Complexity and difficulty are based on required conceptual and procedural understanding in the tasks. Categorization was collected from two professors, compared with each other and each task was given a difficulty level. There are 5 low level, 3 medium level, and 6 high level questions, out of 14 tasks.

Data Analysis

Each interview was coded on following steps:

- Quantitative data was obtained by measuring the variables (e.g., calculator use, calculator fluency, graph of the function, mathematical understanding, solution etc.) being studied along a scale that indicated how much of the variable was present. Researcher coded each interview according to rubric developed. Higher score indicated that more of the variable (such as 2 for mathematical understanding) was present than do lower score (0 for mathematical understanding).
- Categorical data was obtained for: whether they graph on the graphing calculator, the features they used on the graphing calculator, how much they did calculations on the paper, how much they did calculations on the graphing calculator, representations they used in the process of solving task. Categorical data simply indicated that the total number of events (e.g., the features used) researcher found in solving the problem. In order to measure the features students used and the representations they used, researcher used a frequency table and nominal scale to get the percentages.
- Qualitative data: Field notes were taken for each video- taped interview to reflect each research question. Researcher mostly wrote a paragraph or passage, sometimes a label, describing what was seen in each task that is more important. Moreover, researcher, by using the notes from the interviews, compared pair of students who did things/scored on the problems differently. Second, I transcribed all interviews for qualitative data and tried to find some patterns among the groups. I looked at the interview transcripts to examine patterns in students' task solving activities with the graphing calculator.

In order to find out how much using graphing calculator played an important role in high-level tasks, researcher also looked at 3 different item difficulty scores for each group. Accordingly, same trend was found for negative *attitude-high experience*, *negative attitude-low experience* and *positive attitude-low experience* groups (Table 1). These groups' overall scores on medium level tasks were higher than low level tasks. However, scores on high level tasks were lower than medium level tasks. While moving from low level tasks to medium level tasks, these groups were more successful to solve the problems with the help of a graphing calculator; however, there was a decrease from moving medium level tasks to high-level tasks.

On the other hand, positive attitude-high experience group showed different trend (Figure 1). This group scored low on medium level tasks, and almost equal on low and high level tasks. There is no clear evidence to suggest that one group overall score on high level tasks was quite distinctive then medium and low level tasks. Actually, low experience groups (negative attitude-low experience, positive attitude-low experience) scored even lower on high level tasks than low level tasks. Results suggest that the harder the question is, the lower the students' ability to handle the question by using the graphing calculator.

In order to verify quantitative data, I also looked at categorical data for percentage on item difficulties. It means in what percentage low, medium, and high level tasks were graphed on the graphing calculator. When looking at the percentage on item difficulty, there is slightly difference between negative attitude-high experience and positive attitude-high experience groups on high level tasks (Table 2). Other than that, both high experience groups preferred to use the graphing calculator in almost every question. Negative attitude-low experience group has the lowest percentage on three levels. There is clear evidence that low experience students (negative attitude-low experience, positive attitude-low experience) followed same trend; because these groups' calculator use on medium level tasks were higher than low level tasks but there was again a decrease on using the calculator for high level tasks.

When looking at the percentage in terms of students' preference to use the graphing calculator in high level tasks, there is little evidence to say that low experience students showed more flexibility in high-level tasks (Figure 2).

The features(on the graphing calculator) students used in the questions and representations they used were coded to see how much they graphed the function on the graphing calculator and on the paper as well as how much they made calculations on the paper and graphing calculator. For high experience groups (negative attitude-high experience, positive attitude-high experience), there seems to be some dependency on the graphing calculator; because both groups' score for calculations on the graphing calculator were higher than other two groups (Table 3). Positive attitude-high experience group scored highest for calculations on the graphing calculator (%14). However, this group also scored second highest for calculations on the paper. This tendency shows that positive attitude-high experience group followed more flexible ways by switching from paper- pencil method to calculator use or vice-versa.

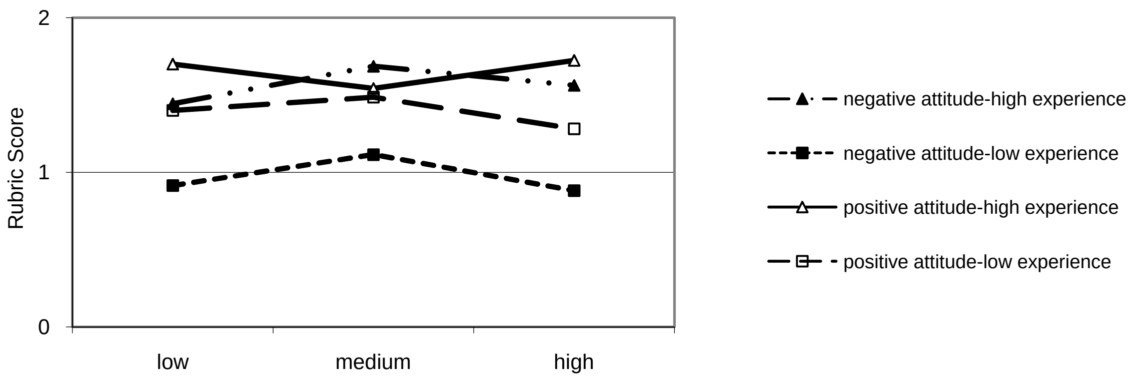

Figure 1. Mean scores on item difficulty

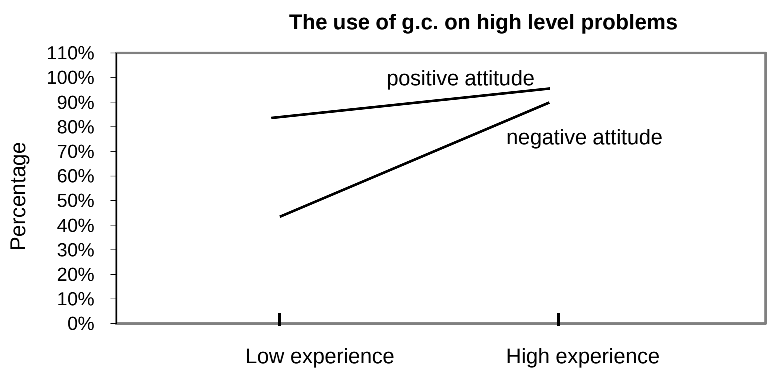

Figure 2. Percentage for the use of the g.c. on high level problems

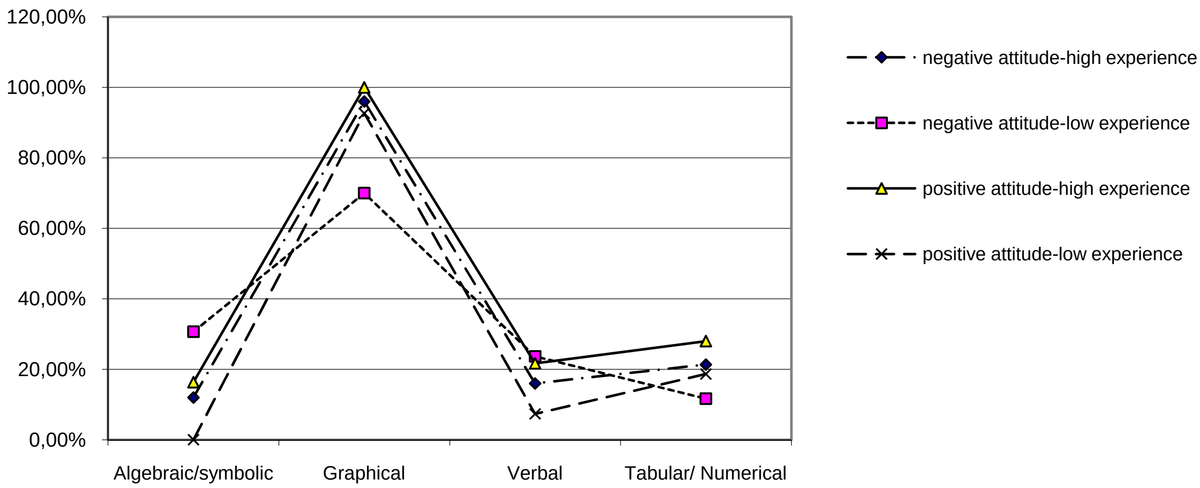

Figure 3. The use of the representations

Table 1. Groups' mean on item difficulty (level of the tasks)

	Item difficulty		
	Low level	Medium Level	High Level
Negative attitude- Low experience	0.91	1.11	0.88
Positive attitude-Low experience	1.4	1.48	1.28
Negative attitude-High experience	1.44	1.68	1.56
Positive attitude-High experience	1.7	1.54	1.72

Table 2. Groups' percentage on item difficulty (level of the question)

	Item difficulty		
	Low level	Medium Level	High Level
Negative attitude-Low experience	40.00%	70.00%	43.33%
Positive attitude-Low experience	70.00%	100.00%	100.00%
Negative attitude-High experience	100.00%	100.00%	93.33%
Positive attitude-High experience	100.00%	100.00%	100.00%

Table 3. Groups' percentage for calculations on the paper and on the graphing calculator

	Did they do calculations on the paper?	Did they do on the g.c. (scientific)?
Negative attitude- Low experience	25.00%	0.00%
Positive attitude-Low experience	4.00%	3.33%
Negative attitude-High experience	4.00%	8.00%
Positive attitude-High experience	13.33%	14.00%

Table 3 shows that negative attitude-low experience group scored highest for calculations on the paper. This group never made calculations on the calculator (scientific mode). This group mostly preferred to use paper pencil work for the solution of the problem. Percentage for calculations on the paper was same for positive attitude-low experience and negative attitude-high experience groups.

Total, 12 graphing calculator features were identified while the students were solving the problems with the graphing calculator. Table 4 shows that students, generally, used GRAPH (80.17%), WINDOW (32.92%), TABLE (31.75%), TRACE (19.83%) functions on the calculator. Especially, high experience groups (negative attitude-high experience, positive attitude-high experience) used TRACE, TABLE, CALC, MATH features extensively. However, these features were not extensive for the other two groups (negative attitude-low experience, positive attitude-low experience).

TABLE feature seemed somewhat important in the interviews that this feature helped a lot to find the y axis and x axis coordinates for the function on the table. Moreover, some students were able to discover any discontinuity on the function (hole) by using this feature. Relatively, many students preferred to get y values from this feature rather than making table on the paper, and giving some values for x to get y values. This pattern was quite extensive among students. I mostly saw that, even in low level questions like one degree function, many students tried to get intersections by looking at TABLE feature or using TRACE feature to spot the intersections on the function graph. Most students solved the problem in this mode by using TABLE to get the x and y values or WINDOW, ZOOM, TRACE features to get a better picture of the graph and look at graph to identify the critical points (maxima, minima, and hole).

Students' preference to use graphical representation (%89.67) was reasonably higher than algebraic, verbal and tabular representations (Figure 3). Second highest representation use was on tabular representations (%19.92). However, there is a clear pattern on using graphical representation that students mostly tried to get the function graph on the graphing calculator and explained to solve the problem verbally by looking at the calculator. Positive attitude-high experience group scored highest on using tabular representations, while negative attitude-low experience group scored highest on algebraic/symbolic representations.

DISCUSSION AND CONCLUSION

This exploratory study investigated students' interaction with complex function graphs in using graphing calculators. In this sense, this study looked at college students' use of graphing calculators and tried to see whether graphing calculators were used efficiently to see different cases and multiple perspectives among complex function graphs, or whether graphing calculators were used only as a mechanical tool to push buttons and get answers (graphs) while working on the tasks.

Research suggests that an instructional method must be as complicated as is necessary to give the students necessary information and learning goals. It was expected that using the graphing calculators will enable to look at the *introduction of complex function graphs* without oversimplification in calculus topics. Tasks were chosen around the first five chapters of Calculus I and administered to students. Students had the option to use the graphing calculator, which allowed to discover their preference for the representation (graphical, analytic, etc.), and their dependency on the graphing calculator. I investigated what kind of patterns/modes of graphing calculator use emerged in students' use of graphing calculators with calculus tasks of varied difficulty.

The findings from the interviews clearly showed that students who had more experience and knowledge on graphing calculators were more flexible in solution strategies than students who had limited experience on the graphing calculator. In other words, high experience groups showed their flexibility in *multiple case examples* by moving from one representation to another (e.g., their flexibility to move from paper- pencil work to graphing calculator use or vice versa).

Students mostly were confused when the tasks were getting complicated; and their translation *skills* did not improve while moving from one representation to another by using the graphing calculator. Moreover, it was clear in interviews that the graphing calculator and mathematical understanding must work together for the solution of the task. Without understanding the task's underlying principles, using the calculator is not enough for students to reach an acceptable outcome. Understanding of the mathematical concept and using the graphing calculator are related to each other, and there is a positive correlation between these two variables. In other words, it is hard to master the task without having initial concept knowledge or a general principle of the concept. Although the order of tasks is arranged in accord with the its complexity and difficulty, giving low level and then high level tasks to the students (especially for low experience students) did not work very well since each task needed some kind of "situation-based" or "case-based" knowledge to be solved.

Interviews clearly showed that students' class experiences regarding graphing calculator use effected students' use of the graphing calculator in the tasks. Students' explanations of the task solving procedures revealed that students seemed to follow the methods they learned in the classes or they followed the methods that are shown by teachers in the classes.

In this study, as indicated by previous research, students used the graphing calculator as a visualization tool to get a clear picture of the function graphs; as a checking tool to see whether the graph they produced on the paper is correct or not; and as a comparing tool to compare different function graphs and see the changes at the same time. However, regarding using the graphing calculator in high level tasks, there is little evidence to say that using the graphing calculator promoted students' understanding of the high level tasks. Rather, using the graphing calculator mostly caused students (especially for low experience students) to produce prepared graphs and copy those graphs on the paper, without finding critical points of those high level function graphs.

High experience groups were better prepared to use the graphing calculator in the tasks and successfully to *go beyond low level knowledge* (when high level tasks were given). The *positive attitude-high experience group* was more flexible in the use of the graphing calculator. Previous experiences with the graphing calculator appeared to allow students to find the answer quickly, without hesitation and error. This group also showed more work on the paper; and explanation was more clear and understandable than in the other groups. This group was the most successful in connecting algebraic work with the result on the graphing calculator. High experience students' use of the graphing calculator seems to fit well in complex tasks and seemed to allow students to create *multiple representations of knowledge*. The results indicated that experience with the graphing calculator was important factor in solving the tasks with the graphing calculator, while attitude seemed to have no effect on task solving steps. Low experience students mostly missed the critical analysis and complexity of high level tasks and only focused on getting the image from the graphing calculator. Although the students had sufficient mathematical knowledge on the tasks, the adequate and necessary skills on using the graphing calculator were needed to understand the tasks' underlying principles and to get the correct solution. For example, *negative attitude-low experience* group was the lowest group for mathematical understanding, solution process of the tasks, and graphing calculator use in high level tasks. However, this group followed more algebraic ways for the solution of the tasks. In other words, low experience and negative attitude on the graphing calculator enforced this group to work on the paper. Low experience groups mostly used the graphing calculator as a visual help to get the graphs; however because of the unfamiliarity with the features on the calculator, low experience students made errors finding critical points of the graphs and made calculation errors on the paper. *Negative attitude-high experience* group members scored higher than *positive attitude-low experience* group members. Results clearly show that in order to use the graphing calculator in complex function graphs to implement the *multiple representations knowledge*, the students need to know characteristics of features on the graphing calculator. They have to have some use of skills and good experience on the machine, not just skills of thinking and skills of knowing the concept.

There is considerable evidence in this study that students who had low experience on the graphing calculator did not give adequate attention to critical analysis of the tasks. That is, because of the limited knowledge on features of the graphing calculator, primary use of the calculator for students with low experience was to graph the functions (by only using Y= and GRAPH); without finding the critical points of the graph, or exploring other points that made the graphs complex and complicated. Thus, it is quite critical for teachers to allow students to use the graphing calculator in class environment. Teachers also must be ready to help students learn how to use the graphing calculator with its full complexity and potential. Moreover, teachers should consider students with different abilities and experience with the graphing calculator and try to minimize these gaps among students.

Some low experience students did not prefer to use the calculator in the tasks since they were not sure what the tasks meant for them. Moreover, some students who did not use the graphing calculator indicated that they already knew the task. Therefore, teachers must give proper attention to mathematical methods they use when graphing calculators are used in the class. It is crucial for teachers to recheck how the subject is taught when the graphing calculator is used. There is a clear indication in the interviews that mere availability of the graphing calculator in the task solving process does not affect or change students' task solving strategies. Rather, the kind of understanding and knowledge students have of the task (students' experience with the tasks) shapes students' approach to tasks. There was a common belief among students that the graphing calculator does not help teach a new concept; but everything must be done on the paper to show that they understood the problem. Thus, teachers should clearly indicate how much graphing calculator use is required and how much written work is needed for the task. Students must get clear direction on how to integrate the use the graphing calculator in the classroom and with the written work required. Students need instruction in how one representation relates to and inform the other.

From this study, it is not possible to say that using the graphing calculator enhanced students' understanding of graphing ability in given high level tasks. Some students were able to get the correct answers (graphs) although they did not understand the task entirely. It did not mean that the use of the graphing calculator gave a flexible understanding of the task; it just gave a quick and prepared answer for the student. Regarding introduction of complex function graphs early, only students with high experience and positive attitude seemed successful. Other than that, there is no clear indication that the use of the graphing calculator improved students' understanding as students move from well simple knowledge to complex knowledge. This study suggests that to introduce domain complexity early can be problematic for the students, combining with the lack of experience on the problem with the lack of experience on the graphing calculator. Some interviews clearly showed that students, sometimes, struggled with the technical details of the graphing calculator (etc. using the parenthesis incorrectly, setting up WINDOW feature incorrectly when different question was given, wrong use of ZOOM and TRACE features while trying to get better picture of the graph, little knowledge about CALC and MATH feature).

Some research assumes that using the graphing calculator will automatically improve students' understanding of the mathematics. It is the major problem in the literature. Rather, research should focus on the ways to better understand how effective use of the graphing calculator can be established in high level of mathematics. Research must focus on broad generalization of the cases by looking across schools and content areas as well as school districts and different grades. There is a need to look and identify cases in broad surveys and interviews, which can help to interpret specific cases.

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An Inquiry Approach to Construct Instructional Trajectories Based on The Use of Digital Technologies

Manuel Santos-Trigo
Center for Research and Advanced Studies, Mexico, MEXICO

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There are diverse ways to construct instructional activities that teachers can use to foster their students' development of mathematical thinking. It is argued that the use of computational tools offers teachers the possibility of designing and exploring mathematical tasks from distinct perspectives that might lead their students to the reconstruction of mathematical relations. In particular, a task that involves the construction of a simple dynamic configuration is used to introduce an inquisitive approach to identify mathematical conjectures or relations and ways to explore and support them. In this process, a hypothetical instructional route is sketched where visual, numeric, geometric, and algebraic approaches are utilized to validate those conjectures.

Keywords: Problem Solving, Computational Tools, Teachers' Knowledge, Instructional Trajectories.

INTRODUCTION

The significant development and availability of several digital tools have opened up diverse opportunities for teachers and students to approach and construct mathematical knowledge and to develop problem-solving strategies. How does the use of particular digital technologies help teachers promote their students' development of problem solving activities? What types of opportunities can the use of the tools offer the learners to engage in mathematical thinking? To what extent does the use of digital technologies become relevant for teachers to trace and explore potential instructional routes to guide their students learning experiences? I utilize the construct "instructional trajectories" to explore and discuss ways in which the systematic use of computational technologies can help teachers trace and examine potential instructional routes to frame and guide their instructional practices. It is argued that the use of the tools becomes important for teachers and students to be engaged in an inquiring or inquisitive approach to reconstruct or develop mathematical relations and enhance problem solving approaches. The hypothetical instructional trajectories that result from examining mathematical task with the use of computational tools are used to guide and promote the students' actual development of their own learning trajectories. In this context, an overarching principle that distinguishes the use of the tools is to conceptualize the tasks in terms of dilemmas or questions that need to be represented and explored through the use of mathematical resources and problem solving strategies. In this context, an inquisitive approach to work on the tasks becomes relevant to illustrate that the use of the computational tools can help teachers develop and employ a set of heuristics (Polya, 1945) that includes a dynamic representation of the task, finding loci, exploring partial goals, using the Cartesian system, quantifying relations, etc. In addition, it is shown that the construction of instructional trajectories can be a teachers' means to review their own mathematical knowledge and problem solving approaches and to openly discuss the paths or routes to approach and solve the tasks in their actual practice.

Correspondence to: Manuel Santos-Trigo, PhD in Mathematics Education, Center for Research and Advanced Studies, Cinvestav-IPN, Mexico, MEXICO
E-mail: msantos@cinvestav.mx

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Instructional Trajectories and Teachers' Mathematical Knowledge

What mathematical, technological, and pedagogical knowledge should the education of high school mathematics teachers include? Who should participate in the designs of educational programs to prepare and upgrade mathematics teachers? What should be the role of mathematics departments or the faculty of education in preparing prospective and practicing teachers? In what types of educational programs should practicing teachers participate in order to revise and extend their mathematical knowledge and to incorporate research results from mathematics education into their practices? Traditional ways to prepare high school teachers normally involve the participation of both mathematics departments and the faculty of education. Mathematics departments offer courses in mathematics while the faculty of education provides the didactical or pedagogical courses. This model of preparing teachers has not clearly provided them solid basis to exhibit the needed mathematical sophistication to interpret and efficiently guide their students in the construction or development of mathematical knowledge. As a consequence, teachers fail to organize and implement meaningful learning activities that foster their students' development of mathematical thinking. Indeed, it is common to read that university instructors complain that their first year university students lack not only fundamental mathematical knowledge; but also strategies or resources to solve problems that require more than the use of rules or formulae (Artigue, 1999, Selden & Selden, 2001).

Many practicing teachers, for different reasons, have not learned some of the content they are now required to teach, or they have not learned it in ways that enable them to teach what is now required. …Teachers need support if the goal of mathematical proficiency for all is to be reached. The demands this makes on teacher educators and the enterprise of teacher education are substantial, and often under-appreciated (Adler, et al., 2005, p. 361).

Davis and Simmt (2006) suggest that teachers' preparation programs should focus more on teachers' construction of mathematical ideas or relations to appreciate their connections, interpretations, and the use of various types of arguments to validate and support those relations, rather than the study of formal mathematics courses. Thus, the context to build up the teachers' mathematical knowledge should be related to the needs associated with their instructional practices. "…[mathematical knowledge] needed for teaching is not a watered version of formal mathematics, but a serious and demanding area of mathematical work" (Davis & Simmt, 2006, p. 295). In this perspective, we argue that teachers' mathematical knowledge can be revised and enhanced within an interacting intellectual community that fosters an inquisitive approach to develop mathematical ideas and to promote problem-solving activities. The core of this community should include the participation of mathematicians, mathematics educators, and practicing teachers. This community should promote collaborative work to construct potential instructional trajectories to guide or orient the teachers' instructional practices. Teachers need to be interacting within a community that supports and provides them with collegial input and the opportunity to share and discuss their ideas in order to enrich their mathematical knowledge and problem solving strategies. Regarding the use of computational tools, Bransford, Brown, and Cocking (Eds.) (1999) state that:

New tools of technology have the potential of enhancing learning in many ways. The tools of technology are creating new learning environments, which need to be assessed carefully, including how their use can facilitate learning, the types of assistance that teachers need in order to incorporate the tools into their classroom practices, the changes in classroom organization that are necessary for using technologies, and the cognitive, social, and learning consequences of using these new tools (p. 235).

In this context, we illustrate the importance of using computational tools to represent and explore various ways of approaching mathematical tasks. The task discussion leads us to show that the use of diverse computational tools offers teachers the possibility of working on mathematical tasks from perspectives that involve visual, numeric, geometric and formal approaches. And as a consequence, they can appreciate or value the advantages associated with the use of the tools and trace potential instructional routes that can guide and foster their students' development of mathematical thinking and problem solving approaches.

Hypothetical Instructional Trajectories and Computational Tools

Problem solving activities that promote the use of digital tools represent an opportunity for practicing and prospective teachers to revise and extend their mathematical competences. What task representations are favored with the use of computational tools? To what extent does the use of computational tools become relevant in identifying and exploring conjectures or mathematical relations? To what extent does the use of particular tools shape a students' way of thinking about tasks and problems? These questions help explore ways of reasoning that can emerge or be developed in problem solving approaches that promote the use of computational tools.

It is argued that the development and availability of computational tools offers teachers and students the possibility of enhancing their repertoire of heuristic strategies to solve mathematical problems and to formulate or reconstruct some mathematical relations. "…guided reinvention [of mathematical knowledge] offers a way out of the generally perceived dilemma of how to bridge the gap between informal knowledge and formal mathematics" (Gravemeijer & Doorman, 1999). It is also important to recognize that different tools may offer distinct opportunities for students to represent and approach mathematical problems. Thus, it becomes relevant to show and discuss not only the potential associated with the use of diverse tools but also ways in which the distinct approaches to the tasks or problems can be related or complemented. For example, with the use of dynamic software, such as Cabri-Geometry or Sketchpad, some tasks can be represented dynamically as a means to identify and explore diverse mathematical relations or conjectures. Later, with the use of a hand-held graphing calculator those conjectures can also be analyzed graphically and algebraically. In this perspective, an underlying principle in any problem solving approach to learn mathematics is to look for distinct ways to represent and explore mathematical tasks and to contrast or discuss mathematical approaches that emerge from the use of diverse tools including the use of paper and pencil (Santos-Trigo, 2007). Thus, the problems or tasks are seen as opportunities to pose and pursue relevant questions that can lead to identify and explore mathematical relations (Schoenfeld, 1998). We identify and document the types of heuristic strategies that appear in problem solving approaches that promote the use of computational tools. In particular, the analysis and discussion of the strategies which emerge as result of constructing and exploring dynamic representations of problems.

Tasks are the key ingredients in promoting and tracing the students' development of problem solving strategies. Here, teachers first need to identify potential or theoretical instructional trajectories (Simon & Tzur, 2004) to frame and then discuss the distinct routes that their students can follow to approach the tasks.

> …[A]n overarching research goal in the field of learning trajectories is to generate knowledge of learning and teaching. Therefore, scientific processes (e.g., documenting decisions, rationales, and conditions; hypothesizing mechanisms; predicting events; and checking those predictions) must be carefully followed and recorded (Clements & Sarama, 2004, p.85).

The identification of potential instructional trajectories involves working on the tasks in detail and exploring various ways to represent and examine the tasks using computational tools. Working on these tasks requires that teachers recognize ways in which mathematics knowledge is connected, and a discussion of what constitutes a valid argument to support mathematical relations. Zbiek, Heid, & Blume, (2007, p. 1170) suggest that in experimental mathematics, computational tools can be used for:

> (a) gaining insight and intuition, (b) discovering new patterns and relationships, (c) graphing to expose mathematical principles, (d) testing and especially falsifying conjectures, (e) exploring a possible result to see whether it merits formal proof, (f) suggesting approaches for formal proof, (g) replacing lengthy hand derivations with tool computations, and (h) confirming analytically derived results.

In this context, we illustrate the ways in which the use of Cabri-Geometry software and hand-held graphing calculators can help teachers represent and apply a set of heuristics to approach and solve the tasks. The solution process is presented around problem solving episodes where relevant questions guide the task solution process. The episodes are part of an inquiry framework that identifies instructional trajectories that teachers can use to structure and to guide the development of their lessons (Santos-Trigo & Camacho-Machín, in press). The task is representative of a set of problems that were used in a problem-solving seminar in which high school teachers used Cabri-Geometry software to identify and discuss potential learning trajectories.

The task involves the construction of a dynamic configuration that leads to relate a tangent circle to the study of two conic sections: The parabola and the hyperbola. Here, the use of two tools, the dynamic software and a hand-held calculator, becomes relevant to complement and relate ways of reasoning that involve visual, numeric, geometric, and algebraic approaches. The task is a variant of what Gravemeijer & Doorman (1999) call context problems since the problem solver has the opportunity to reconstruct a set of mathematical relations as a result of representing and examining mathematical objects dynamically.

An example: On the Construction of Possible Instructional Routes

An overall principle associated with the construction of potential instructional trajectories is that all problem representations should be constantly examined and interpreted in terms of responding questions that involve the use of mathematical resources or problem solving strategies. Thus, the formulation of questions and the search for diverse ways to respond to those questions are crucial activities that shape the development of potential routes of instruction. The next example illustrates ways in which the use of a tool (Cabri-Geometry software) can offer teachers the opportunity of reconstructing a set of mathematical relations that involves contents associated with the study of the conic sections. The problem solving episodes emerge within a community in which high school teachers together with mathematicians and mathematics educators worked on series of tasks to identify potential instructional routes and to discuss the strengths and limitations of using several computational tools. Thus, the goal is to characterize the community or group's problem solving approaches that emerged during the development of the sessions rather than analyzing in detail the individual contribution or performances of the participants.

The initial task. Given a line L and a point P not on the line (Figure 1) construct a dynamic configuration[1] that involves other mathematical objects and identify properties or mathematical relations that result from moving particular elements within the configuration.

This is an open activity where the construction of a geometric configuration might involve various initial routes. Thus, some departure attempts may include, for example: (i) Placing a point Q on line L and constructing an equilateral triangle with side PQ (Figure 2a) and add other objects and start moving some of them to identify invariants or changes produced as a result of that motion on other objects within configuration; or (ii) Situating also point Q on line L and drawing a circle that passes through point P and is tangent to line L at point Q (Figure 2b). In the latter, the initial goal can be to identify mathematical relations around the construction of a circle tangent to line L that passes through point P (Figure 2b). Thus, to draw a tangent circle to line L that passes through point P is the point of departure to identify and explore mathematical relations.

First episode: Dynamic representation and partial goals. An important strategy that is used often in problems or tasks that can be represented dynamically is to identify and analyze loci that result when some components (points, segments, lines, etc.) of the problem representation are moved along well defined paths. Thus, the construction of a dynamic representation of problems, whenever possible, is a heuristic that need to be considered in problem solving approaches. The use of the software for the construction of a dynamic representation is based on conceptualizing the problem in terms of relevant mathematical properties. What does it mean to draw a circle that passes through a point and is tangent to a given line? In this task, a heuristic, that involves focusing on a partial goal of drawing a circle with center point C situated on a perpendicular to line L and radius

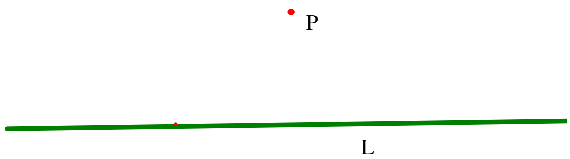

Figure 1. Construct a dynamic configuration that includes a given line L and a point P out of the line

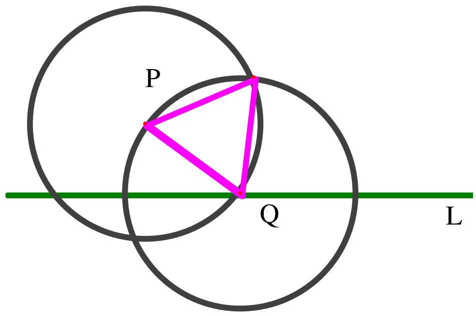

Figure 2a. Drawing an equilateral triangle with side PQ

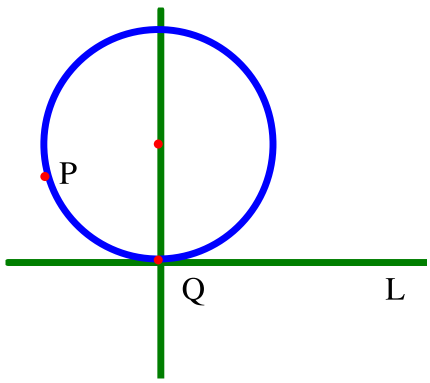

Figure 2b. Drawing a circle that passes through point P and is tangent to line L

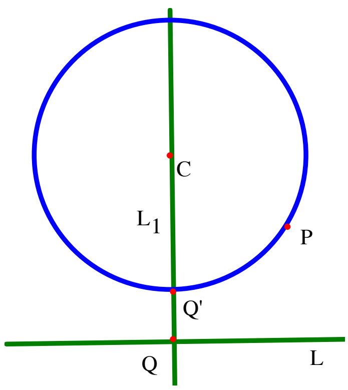

Figure 3. The center of the circle must lie on the perpendicular line to L

[1] A dynamic configuration consists of simple mathematical objects (points, segments, lines, triangles, squares, circles, etc.) arranged in such a way that one can move a particular element within the configuration and observe what happens to others elements as a result of that movement.

segment CP (Figure 3), is pursued to identify ways to construct a tangent circle.

A visual approach. The circle (Figure 3) satisfies the condition that passes through point P but it is clear that it is not tangent to line L. However, when either point C or point Q are moved along lines L_1 or L respectively, there will be visually a position for the circle in which it is tangent to line L (Figure 4a and 4b). This visual solution is useful to make explicit a set of properties associated with the construction of the tangent circle.

Second episode: Identification of geometric properties, a bisector approach. What geometric properties does the tangent circle satisfy? Is there any particular relation between the center of the tangent circle and the tangency point and point P? The visual approach becomes important to identify relevant properties embedded in the representation. It is observed that when the circle is tangent to line L (Figures 4a and 4b), then d(C,Q) must be equal to d(C,P). Based on this fact, the center of the tangent circle must be the intersection of the perpendicular bisector of segment QP and L_1 (perpendicular line to L that passes through Q) (Figure 5).

The above solution involves an Euclidean construction since it can be drawn with straightedge and a compass. With the use of the software it is possible to identify and examine the path left by particular points when other points are moved within the representation. What is the locus of point C' (center of the tangent circle) when point Q is moved along line L? (Figure 6). The locus of point C' when point Q is moved along line L seems to be a parabola; however, it is important to prove that the locus satisfies the definition of this conic section.

Third Episode: The use of empirical and formal arguments. To verify empirically that the locus is a parabola, we choose a point R on the locus and assume that point P is the focus and L is the directrix of the parabola. We calculate the distance from R to P and from R to line L and notice that for distinct positions of point R both distances are equal. Figure 7 shows two positions of point R. In this example, another heuristic method appears: To measure attributes (lengths, distances, areas, perimeters, angles, slopes, etc) associated with particular objects in order to identify invariants. In this case, the use of the software helped us to measure and compare distances from a point on the locus to line L and from the point to the center of the tangent circle.

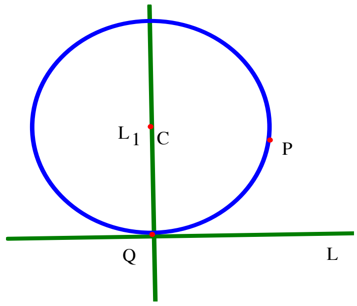

Figure 4a. Moving point C along line L_1 to visually identify the tangent circle to line L

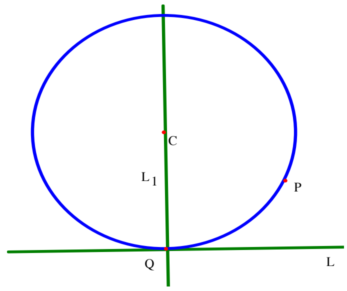

Figure 4b. Moving point Q along line L to visually identify the circle tangent to line L

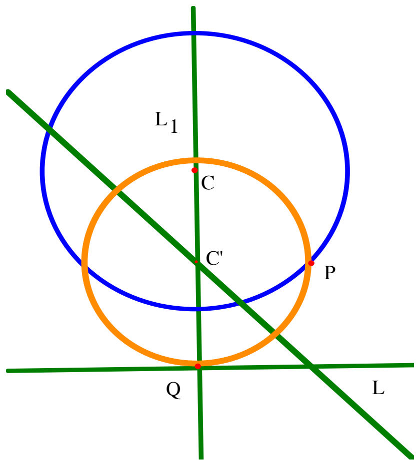

Figure 5. The center of the tangent circle is the intersection of the perpendicular bisector of PQ and the perpendicular line to L that passes through point Q

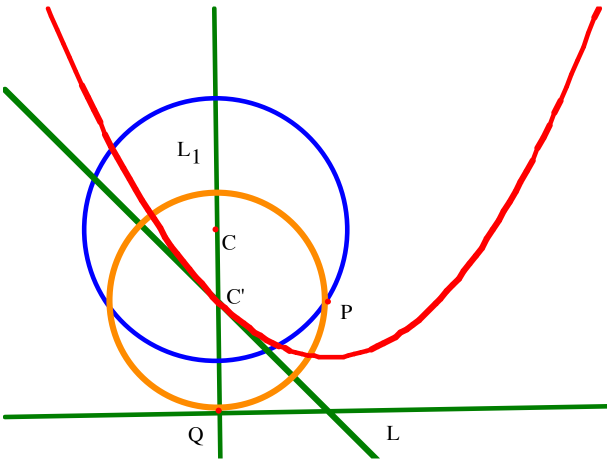

Figure 6. The locus of point C' when point Q is moved along line L is a parabola.

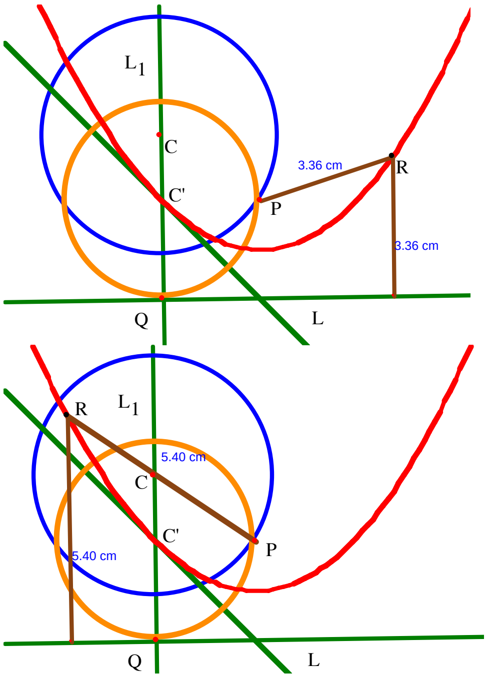

Figure 7: Verifying the definition of parabola

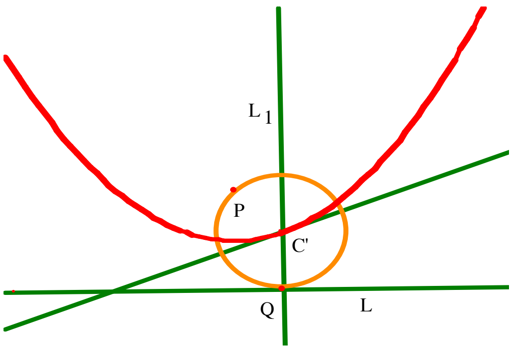

Figure 8: Using the definition of perpendicular bisector to show that the locus satisfies the definition of the parabola

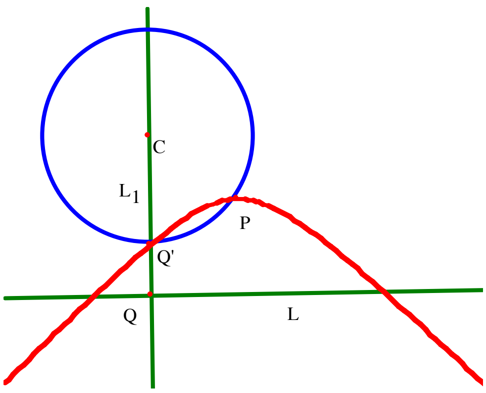

Figure 9. the locus of point Q' when point Q is moved along line L.

A geometric argument to show that the locus is a parabola is based on observing that point C', which generates the locus, is on the perpendicular bisector of segment QP (Figure 8). Therefore, the distance from point C' to point P is equal to the distance from point C' to line L (the definition of perpendicular bisector). Therefore, the locus of point C' when point Q is moved along line L is a parabola.

Fourth episode: Connections. On figure 3 it is observed that the circle intersects the perpendicular line to L at Q' and when point Q is moved along line L, then point Q' describes a unique path. What is the locus of point Q' when point Q is moved along line L? Again the software helps us identify this locus (Figure 9).

When point Q moves along line L there are two positions, the intersection points of the locus and line L, in which the circle is tangent to line L. Thus, the center of each tangent circle will be the intersection points (C' and C") of the perpendicular lines to line L drawn from the intersection points of the locus and line L and the perpendicular line to L_1 that passes by point C respectively (Figure 10).

With the use of the conic command from the software, we select five points on the locus and draw the corresponding conic section (Figure 10). In this case the conic section is a hyperbola. To show that the locus satisfies the definition of hyperbola, we draw a perpendicular line to L that passes through point P. This line intersects the locus at point P' and point M is the midpoint of segment PP'. We draw the perpendicular line to line PP' that passes through point M and a circle with center at point M and radius MP. This circle intersects that perpendicular at point K. We draw a perpendicular to line MK that passes through point K and a perpendicular to line PP' that passes through point P, these lines get intersected at point K'. We draw a circle with center point M and radius MK'. This circle intersects line PP' at points $F_1$and F_2. F_1 and F_2 are the foci of the hyperbola (Figure 11). This geometric construction can be validated through an algebraic approach (Santos-Trigo, et, al., 2006).

Again to show empirically that the definition of hyperbola is satisfied, we take a point S on the locus and calculate the absolute value of the difference between the distances from that point to each focus. It is observed that for different positions of point S the difference is a constant (Figure 12).

It is also observed from figure 10 that the loci of points C' and C" (centers of the tangent circles), when point C is moved along line L_1, is a parabola (Figure 13).

The argument used to show that the locus is a parabola is based on the fact that points P and R are on the circle with centre C', therefore, d(C',P) = d(C',R). That is, the focus of the parabola is point P and its directrix is line L.

A triangle approach. Another way to draw the tangent circle to line L that passes through point P involves drawing Q on line L, a circle with center point Q and radius QP, and a parallel line L' to line L that passes

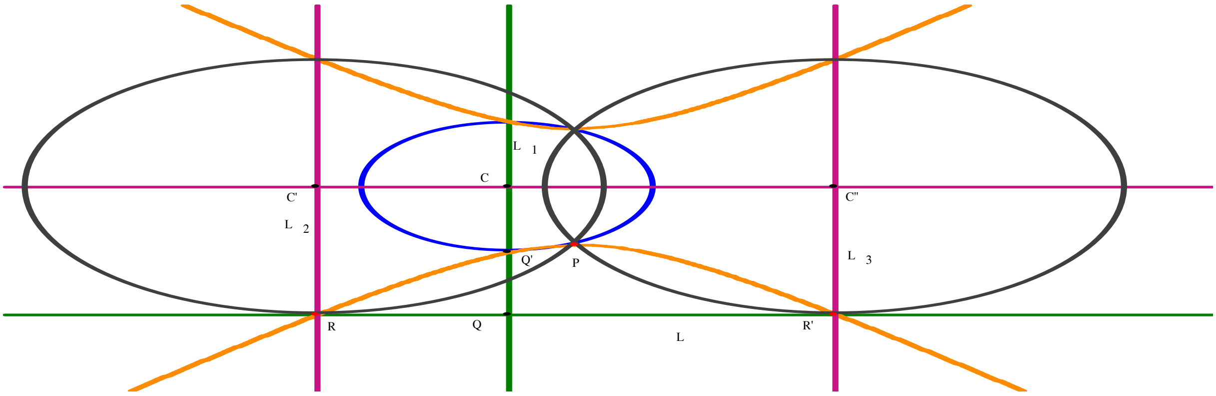

Figure 10. Drawing the tangent circles to line L

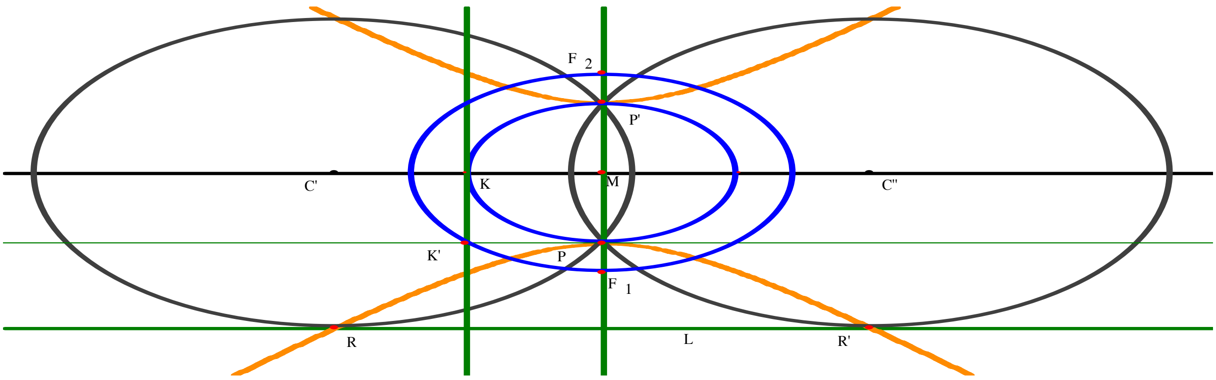

Figure 11. The locus satisfies the definition of hyperbola

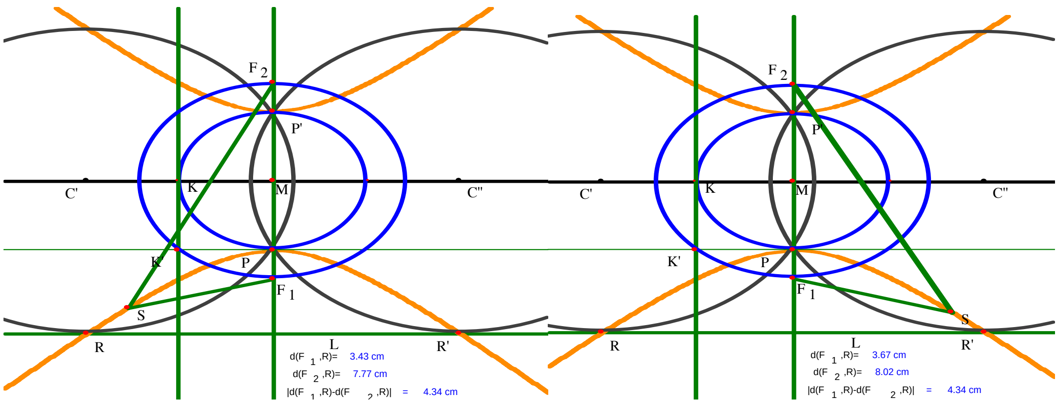

Figure 12. For distinct positions of point S on the locus the definition of hyperbola is satisfied

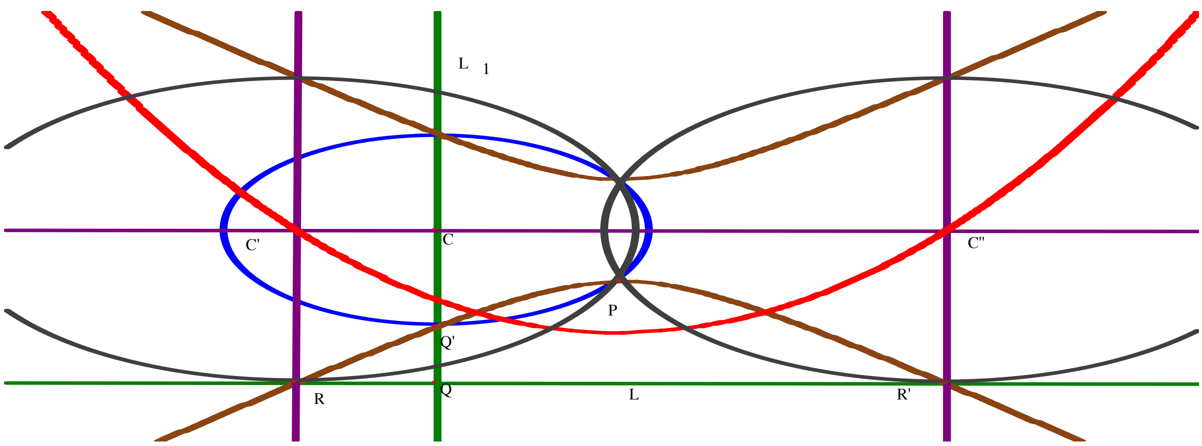

Figure 13. The path left by points C' and C" when point C is moved along line L1 is a parabola

through point P (Figure 14). Thus, the tangent circle to line L that passes though point P is the circle that inscribes triangle PQR. The center of the tangent circle is then the intersection of the perpendicular bisectors of the sides of triangle PQR (Figure 14a).

It is observed that when point Q is moved along line L, a family of triangles and circles tangents to L appeared. At what position of Q does triangle PQR become equilateral? To respond to this question, we identify the intersection of the heights of sides PQ and QR (orthocenter) and observe that the loci of point C and O when point Q is moved along line L are two parabolas (Figure 15). Thus, at the intersection point of those parabolas is the position where points C and O (the circumcenter and orthocenter) coincided. There the triangle PQR is equilateral (Figure, 15a).

A pattern approach. Yet, another approach to draw tangent circles to line L that pass through point P involves a construction pattern. The pattern is based on constructing initially a perpendicular line to L that passes through point P. This perpendicular line intersects line L at point Q. Thus, the midpoint of segment PQ is the center of the tangent circle to line L that passes through point P (Figure 16).

The grid on Figure 16a was constructed by drawing a perpendicular line to line PQ that passes through point C. This perpendicular intersects the circle with center C at point R. From point R a perpendicular to line L is drawn. By using the command *Reflection*, all the other lines are constructed. It is also observed that if line L and line PQ are the axis of a coordinates system, then the centers of the tangent circles to line L are given as C(0, 1); D(2, 2); E(4, 5), etc. This sequence leads us to observe that sequence of the first entries (0, 2, 4, 6, etc.) has constant difference of 2; while the second difference of the second entries (1, 2, 5, 10, 17, 26, etc.) was also of 2. Here, if segment QC is taken as one unit, then the equation of the curve that passes through the centers of the tangent circle to L is $y = \frac{x^2}{4} + 1$ which represents a parabola equation.

It is observed that a simple task that involves drawing a tangent circle brings into the discussion not only the use of diverse mathematical concepts but also the application of distinct mathematical processes and problem solving strategies to formulate and pursue relevant questions.

An algebraic approach. The initial task can also be represented algebraically. A heuristic here will be to set the Cartesian system in such a way that the algebraic calculations can be made easy. Thus, we choose the x-axis as the line L and the y-axis to be the perpendicular line to L on which the centre of the tangent circle is located. On Figure 17 line L is the x-axis and the perpendicular line to x-axis that passes through point Q is the y-axis, point P has coordinates (x_1, y_1) and M is

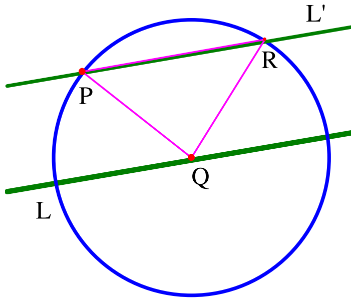

Figure 14. Drawing a circle with centre at Q and radius QP

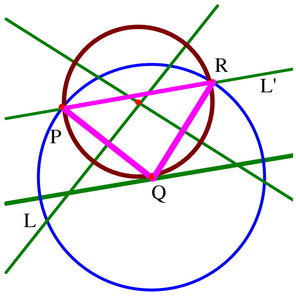

Figure 14a. The intersection point of the perpendicular bisectors of segment PQ and QR is the center of the circle tangent to L

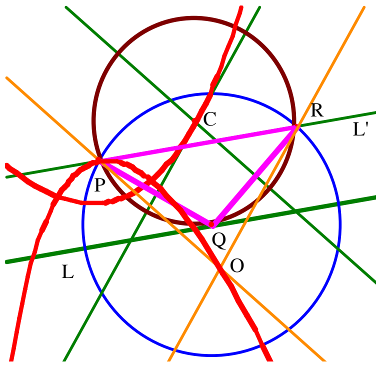

Figure 15. When triangle PQR does become equilateral?

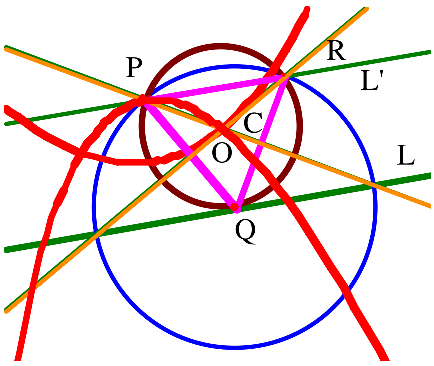

Figure 15a. Triangle PQR is equilateral when the circumcenter and orthocentre get intersected

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the midpoint of segment QP and has coordinates $\left(\frac{x_1}{2}, \frac{y_1}{2}\right)$.

Based on this information, the slope of line QP is $m = \frac{y_1}{x_1}$ and the slope of the perpendicular bisector of segment PQ is $m_1 = -\frac{x_1}{y_1}$. Therefore, the equation of the perpendicular bisector of PQ can be expressed as: $y - \frac{y_1}{2} = -\frac{x_1}{y_1}(x - \frac{x_1}{2})$, and we take $x = 0$ then $y = \frac{x_1^2}{2y_1} + \frac{y_1}{2}$. Thus, the centre of the tangent circle will be $\left(0, \frac{x_1^2}{2y_1} + \frac{y_1}{2}\right)$. A simpler approach can also be applied by recognizing that the point P needs to satisfy that d(Q, C) = d(C, P). That is, if C(y, 0) and P (x_1 y_1) then we have that $y = \sqrt{x_1^2 + (y_1 - y)^2}$ which implies that $y = \frac{x_1^2}{2y_1} + \frac{y_1}{2}$

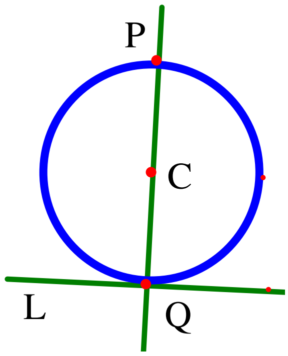

Figure 16. Drawing a tangent circle to line L that passes through point P

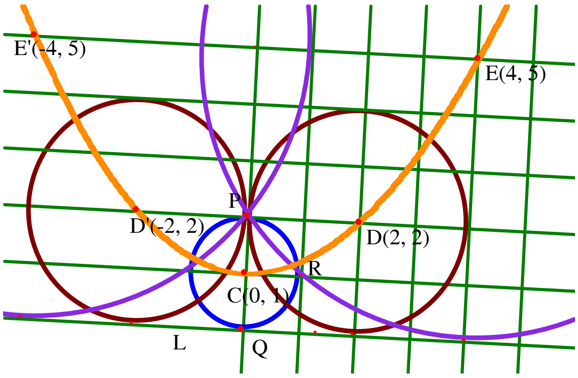

Figure 16a. Drawing other tangent circles based on a symmetry pattern of the initial construction

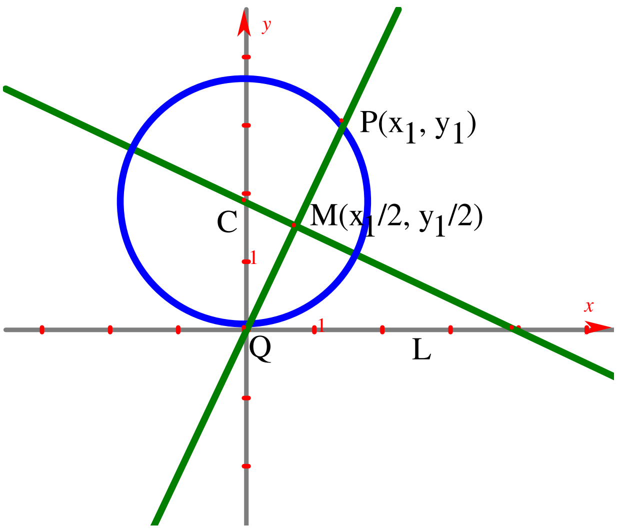

Figure 17. Approaching the task algebraically

Commentary: The dynamic representation of mathematical objects or problems is a heuristic that can guide the problem solver in the search of mathematical relations. The partial goal of drawing a circle with its center on a perpendicular to line L and radius the distance from the center to the given point (P) becomes relevant to visualize and examine properties of the solution. Based on those properties the tangent circle was constructed. In addition, the dynamic configuration is used to relate the problem to other mathematical objects (parabola and hyperbola). The problem solver must show and justify that the objects that are visualized through the loci satisfy the corresponding definitions. To accomplish this task, an important heuristic that gives an empirical verification is to measure distances between objects in order to observe invariants when particular objects are moved along specific paths. In this case, the process of measuring and comparing distances was a relevant strategy to verify empirically the definition of both conic sections. In addition, the dynamic representation of the tasks becomes a departure point to identify and examine a set of relations that emerge as a result of moving mathematical objects within the same configuration. The use of the software not only can help teachers and students identify important mathematical relations; but also to provide a route to support or prove them. In this task, the route involves ways to first visualize a relation, later to verify it empirically and finally to use geometric and algebraic arguments to prove it.

Schoenfeld (1985; 1992) reports that in general students tend to copy or redraw figures that appear in the statement of the problems and use them to make conjectures or to identify relations. With the use of paper and pencil the sketches or representations drawn not necessarily capture the objects' precision and students often assume or perceive false conjectures or statements. However, the use of the software allows us to accurately represent and draw mathematical objects. Also these representations can facilitate the process of looking for mathematical relations and the visual exploration of their plausibility. In addition, with the use of the software it is easy to change size or positions of the original objects to explore whether invariants or conjectures are maintained for a family of those objects. For example, in the task, the position of point P can change and the way to construct and generate the conic sections is preserved. As a consequence, with the use of computational tools, the problem solver or students might develop a method of thinking of how to represent and approach a family of isomorphic problems.

CONCLUDING REMARKS

I use the construct "hypothetical instructional trajectory" to identify and examine potential routes that teachers can initially trace with the use of computational technology. How can an instructional route be constructed? Who can participate in such construction? And what is the role of the use of computational tools in constructing them? The initial task is used as a departure point to construct a dynamic configuration that leads us to constantly formulate and explore questions from diverse angles or perspectives. In this process, there is an attempt to identify crucial themes and ideas that teachers and researchers could relate and consider in their practice and research agendas:

Inquiry Process. There is ample evidence that the use of the tool offers the problem solver the opportunity of becoming engaged into an inquiry process that guides him/her to look for mathematical relations and means to support them (Santos-Trigo, et, al., 2007). Thus, learning mathematics and problem solving are processes in which students constantly pose or formulate questions to identify, examine, and support conjectures or mathematical relations. In the task discussed, there is no initial given question or problem to solve, instead the problem solver begins by assembling or putting together a geometric configuration which becomes the source to be engaged into an inquiry process in order to develop or reconstruct a set of mathematical relations. The use of the tools provides, in general, instantaneous response to the problem solver' s queries and as a consequence it can foster the discussion of results within the learning community. Thus, such community should not only value or pay attention to the emerging relations or results; but also to the search for arguments to support them.

Heuristic Strategies. An important heuristic associated with the use of the tools is to think of the tasks or problems in terms of mathematical properties. If the problem solver is to represent the problem dynamically it is necessary to identify relevant mathematical properties to guide the construction of that representation. What does it mean to draw a circle that is tangent to a given line? Is there a relation between the tangency point and the center of that circle? These are examples of questions that helped problem solvers to represent the task with the use of the tools. In addition, other heuristics such as identifying and exploring partial goals, assuming the task solved, or finding loci of particular objects are easy to implement with the use of the tools and are useful to explore and generate mathematical relations.

The Use of Various Computational Tools. The efficient use of a tool to represent and explore mathematical problems is a process in which the problem solver identifies and recognizes the power and advantages to think of a given problem in terms of the software commands. The use of the tool also shapes the way students or problem solvers think of the problem (Kaput, Lesh, Hegedus, 2007). Since each tool offers particular advantages to deal with each problem, then it is relevant to utilize more than one tool to enhance the teachers or students' ways to approach and solve problems (Santos-Trigo, et, al., 2006). For example, the use of dynamic software facilitates the construction of dynamic representations of objects while the use of hand-calculator offers certain advantages to represent and deal with the problem algebraically. Thus, it is important for the problem solver to utilize various computational tools to search for and complement different approaches to the problem.

Curriculum Fundamentals. The task presented in this paper was discussed during two problem-solving sessions of three hours each. Some of the approaches emerged during the development of the session; but other ideas and task extensions emerged out of the sessions' work where the participants continued commenting, exchanging, and testing other task ideas. Here, the participants pointed out that to promote their students work along the lines that appeared while approaching the task, it is necessary to reduce the curriculum contents that teachers are asked to cover in their regular courses. In this perspective, the participants suggested that the contents to be studied need to be structured and organized around fundamental mathematical ideas and problem solving processes that are relevant for students to construct and develop in depth (NCTM, 2000). It is also recognized that the use of the tools can help students to foster strategies and ways to formulate and pursue questions and eventually identify a set of mathematical relations.

Teachers' Use of the Tools and Mathematical Knowledge. How should in-service teachers incorporate the use of computational tools in their instructional practices? There is evidence that the construction of potential instructional trajectories is a problem solving activity in which the teachers have the opportunity of recognizing the potentials and limitations associated with the use of the tools to represent and explore mathematical relations (Santos-Trigo, 2006). In addition, the use of the tools seems to promote the discussion of mathematical contents in terms of identifying potential routes for students to comprehend and apply the acquired knowledge. For example, in the initial task, the appearance of the conic sections while drawing a tangent circle not only promoted the discussion of the properties of those figures; but also the consideration of instructional paths in which the study of the conic sections could be structured or organized for students. Thus, a clear hypothetical route that emerges while approaching the task might focus on guiding the students to initially construct a dynamic representation of the problem to comprehend and make sense of relevant information associated with the problem situation. Later, the configuration becomes a source or instance to identify visually a set of relations or conjectures whose plausibility and validity can be validated empirically (quantification of those relations). Further, the use of tools not only facilitates the visualization and exploration of mathematical relations, but also provides important information to represent and analyze the relations in terms of geometric properties or algebraically.

The use of computational tools offers teachers the possibility of guiding their students to develop an inquiry approach to interact with mathematical ideas or problems. In this process, problem solving and constructing mathematical ideas require more than responding particular questions, they demand that the students become engaged into a reflection activity to search for multiples ways to solve problems or to explain mathematical ideas, and to look for possible connections and means to communicate results.

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A Comparison Study of 9th Graders in the U.S. and Albania

Sofokli Garo
University of Alexander Moisiu, Durres, ALBANIA

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The purpose of this research is to compare American and Albanian students' achievement in Algebra 1 and to identify the educational practices that influence students' achievement in each country. The study compared algebraic solving abilities of 242 ninth-grade American students in Grand Forks (U.S.) and 219 students in Durres (Albania). The data collection instrument consisted of a Texas publicly-released standardized test and a student questionnaire. The test focused on the Algebra 1 knowledge covered during the academic year 2006-2007, whereas the questionnaire attempted to measure students' perceptions of educational practices exerted in their classrooms and communities. The results showed that Albanian students outperformed American students in both overall achievement and algebraic representation skills. The first difference was significant at .05 level whereas the second difference was not significant. Albanian students seem more involved than their American peers in practices, such as studying textbooks for understanding and test-taking, reading for enjoyment, and learning for the next day. Compared to Americans, Albanian students seem more satisfied with being in school and learning mathematics, and view mathematics as conducive to entering a college or university. American students, on the other hand, seem more concerned than Albanians about using and requiring calculators, spending out-of-school time with friends, sport activities, and electronic games. For them studying mathematics is about understanding other classes of high school curriculum Algebraic achievement of Albanian and American students seem to be affected by four and six educational practices, respectively.

Keywords: Students' Achievement, Educational Practices, Instruction.

INTRODUCTION

After a rich experience with teaching algebra in his home country, Albania, the author of this study had the opportunity to tutor, observe, and teach this discipline in the U.S. A number of differences related to educational practices, exercised in school and out-of-school environments of both countries were observed. These differences led in generating the following questions: Do these differences result in algebra achievement differences? Are there other differences in cultural educational practices, which also affect achievement of students in both countries? This study provides an endeavor of answering these questions.

Correspondence to: Sofokli Garo, PhD in Mathematics Education, University of Alexander Moisiu, Durres, ALBANIA
E-mail: sofokli.garo@und.edu

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Many previous studies have focused on cultural educational practices that are associated with students' learning. Their authors have pointed out that a classification of cultural practices into instruction-related and non instructional-related educational factors produce a better understanding of the effect of cultural experience in mediating learning. The proposed suggestion has been useful in designing both international and multinational large-scale studies. This study was designed to make a contribution to this field by comparing Algebra achievement of ninth grade students in the U.S. and Albania, as well as by identifying the educational practices within each culture that may affect student learning.

The topic of this study was Algebra 1 because this mathematics course is considered a gateway to further mathematical preparation of almost all high school students in every country. American and Albanian students' achievement in Algebra 1 was measured by using a standardized test, commonly used in the U.S. The examination of educational practices was determined by obtaining students' perceptions about educational practices. In the student' questionnaire items were divided into two categories, instructional and noninstructional. The first category included students' perceptions of teacher strategies, use of textbooks and use of calculators. The second category included students' believes about the organization of their school-days, students' attitudes toward school and mathematics, and their feelings about home environment.

The results of this study will allows teachers of both countries to compare best practices and to further develop their own improvements, ones appropriate for their school systems.

Purpose of the Study

The first purpose of this study was to compare algebraic achievement of students in the U.S and Albania. This comparison was made at two levels:

1. Students' mastering of the overall algebraic achievement.
2. Students' mastering of algebraic representation skills.

The second purpose was to compare the instructional and noninstructional practices of the two countries, as well as to identify educational practices which contribute toward overall algebraic achievement of students in each country.

LITERATURE REVIEW

Algebraic achievement

The overall algebraic achievement

TIMSS International Studies show that Japanese and Singaporean students outperform US students (Beaton et al., 1996). TIMSS students from some European countries, such as Germany, Belgium and Holland also display higher levels of achievement compared with that of the U.S. students (Lemke & Gonzales, 2006; Stigler & Hiebert, 1999). In 2003, the U.S. achievement in mathematics literacy and problem solving was lower than the average achievement for most industrialized (OECD) countries. The United States also performed below the OECD average on each mathematics literacy subscale representing a specific content area (NCES, 2004).

A review of research indicates that there is a lack of information with regard to Albanian students' participation in international competitions or comparisons. The most recent information is related to Albania's participation in PISA 2000, where Albanian students scored second worst in the international assessments of student learning outcomes in reading, mathematics and science literacy (OECD, 2001).

Students' Preference of Representation Models

National Assessment of Educational Progress showed that most seventeen-year-olds in the U.S. could perform basic arithmetic operations, but nearly all of them failed to solve multi-step problems that require symbolic algebra (Dossesy et al., 1988). Healy & Hoyles (2000) found also that using algebraic means in order to justify and explain problem-solving procedures is really hard for high school students. In their attempts to solve algebra word problems many American secondary students prefer to justify and explain mathematical solutions in a verbal mode (Cai, 2004).

The Institute of Pedagogical Studies in Albania recently conducted a study to examine, among other things, students' work with algebra word problems given on the National Leaving Examinations. The findings showed that the vast majority of Albanian students preferred a numerical mode of representation; more specifically, 37 percent of answers were in verbal and diagram mode, and only 11 percent were represented in an algebraic mode (Lulja, 2003).

Instructional and Noninstructional Factors that

Affect Algebra1 Achievement

A review of previous research was conducted in an attempt to examine the differences between educational practices used in the two cultures as well as the role of these practices on student achievement.

Instructional Factors

Several studies have examined the relationship between students' academic achievement and students' beliefs about instructional factors, such as instructional strategies, use of textbooks, and use of calculators.

Instructional *strategies:* Students' perceptions of what kind of instructional strategy their teachers employ in classroom have an important influence on their responses to school. Studies have shown that American algebra teachers vary substantially in terms of the content they teach and the cognitive approach they pursue (Farrell & Farmer, 1998).Thus, Stigler and Hiebert (1999) underline three main characteristics of American teaching of high school algebra. First, American teachers use a variety of teaching strategies. Students may work together as a class or break off into small groups. Second, American teachers spend nearly 87 of the class time by working with their students and much of it is spent with individual students or small groups, rather than with the class as a whole. Third, most teachers in the U.S. use visual devices to focus students' attention. As they finish each part of their oral presentation, they often erased that part of the written material and moved to the next item.

In Albania, when teachers grade individual students, often they call students on the board for completing an exercise; the rest of the class observes (Musai & Boce, 2003). Other research on the teaching of algebra provide data, which show that Albanian teachers tend to spend a lot of instructional time on examining algebraic reasoning of eighth and ninth graders (Lambiri, 2004; Musai & Boce, 2003).

Textbooks. Between 67 and 90 percent of all classroom instruction in any subject and at any level consists solely of textbook applications (Muth and Alvermann, 1992). Schmidt et al. (2001) found that American ninth graders do not devote adequate time to studying their textbooks, and this attitude is negatively correlated to their achievement. On the other hand, Albanian researchers (e.g., Llambiri, 2004) have documented a strong influence of textbooks on mathematics attainment of Albanian students.

Calculators. A comprehensive review of the research on handheld graphing calculators in secondary mathematics instruction indicated positive correlations between use of calculators and mathematics achievement. For example, Telese (2000) found that students in the U.S. who more frequently used calculators during mathematics lessons showed higher algebra test scores. Other authors indicated that there is improved student conceptual understanding when students use graphing calculators with curricula specifically designed to take advantage of the technology (Burrill et al., 2002; Ruthven, 1990). The Heller and Paulukonis' study (2000) reached the same conclusion on the domain of Algebra.

Albanian teachers do not seem to rely on the calculators when they develop their lessons. Furthermore, they do not encourage their students to use calculators on tests (Llambiri, 2004).

Noninstructional Factors.

Stigler and Hiebert (1999) assert that, besides instructional factors, there are other noninstructional factors, such as school day organization, students' attitude towards school, students' attitude towards learning mathematics, and home environment, which tend to affect students' leaning outcomes.

School-day organization. Research in cognition (e.g., Martin et al., 1995; Stevenson & Lee, 1990), has shown that American out-of-school students' experiences have a substantial effect on their learning. With respect to students' management of free time, in about half the TIMSS 1995 countries, including the U.S., the highest mathematics achievement was associated with watching from one to two hours of television per day. This was the most common response, reflecting from 33 percent to 54 percent of the students for all countries (Martin et al., 1995).

Two recent studies (Mita, 2001; Rrapo, 2006) have examined the school day organization of ninth graders in Albania. Based on PISA 2000 study results, for Albanian students, watching television less than one hour per day, generally was associated with lower average mathematics achievement than watching one to two hours (Mita, 2001). In another study, Rrapo (2006) attempted to examine the association of high school students' achievement with the noninstructional time, spent on learning. He found a significant positive relationship between these variables. The relationship was found to be even stronger when the time was spent on doing written homework.

Students' attitude to school. Students' attitude toward going to school has been given various labels, such as, students' sense of belonging at school, social aspect of schooling, etc. Consideration of students' sense of belonging at school has been shown as an effective way for measuring the relationship between students' attitude toward school and student achievement. Following this approach, PISA 2003 study showed that higher scores in the variable of "belonging at school" were associated with higher scores on OECD students' achievement (Nohara, 2001). In addition, results of TIMSS 1995 study showed that the American "student's aspirations for future education" was one of the strongest school-level predictors of achievement (Martin et al., 1995). Sociologists have found that students in the United States focus more on the social aspects of school than the academic ones; for them school is about friends (Coleman, 1988; Goodlad, 1982).

PISA 2000 results show that Albania is among the four countries, which scored lowest on students' sense of enjoying school. More specifically, students' sense of belonging to school in programs designed to provide direct access to the labor market, tends to be lower than in academically oriented programs (Mita, 2001). The social aspect of schooling is important for Albanian students as well. But, many students who enter high school level seem more focused on the academic aspect of schooling. They want to complete it successfully in order to enter a college or university. Their ultimate goal is to find a good job that will lead to a higher standard of living (The World Bank, 2005).

Students' attitude to learning mathematics. Ma (1999) has demonstrated that primary among the variables that determine achievement in mathematics (AIM) is attitude toward mathematics (ATM). The research literature, however, has failed to provide consistent findings regarding the relationship between ATM and AIM. Thus, a number of researchers have demonstrated that, in the samples of the U.S students, the ATM-AIM correlation is quite low, ranging from zero to 0.25 in absolute value, concluding that the ATM-AIM relationship is not of practical significance (Wolf & Blixt, 1981).

Results of PISA 2000 study show that Albanian students with greater interest in and enjoyment of mathematics tend to achieve better results than those with less interest in and enjoyment of mathematics (Mita, 2001).

Home environment. Numerous sociological studies have found that the home environment has an impact on achievement in the United States (Riordan, 2004, Kutner, 1996). Referring to the TIMSS 1995 results, Martin et al. (1995) point out, that the parental academic pressure was found to be significant in the U.S., with higher pressure generally being found in the higher-achieving schools. In addition, these authors report a positive relationship between achievement and the presence of academic aids, such as computers, study desks, and dictionaries, at American students' homes.

That most of Albanian high school students seem more focused on the academic aspect of school probably has much to do with the involvement of parents in children's education. Albanian parents regard doing well in school as the single most important task facing their children. This attitude is expressed, for example, on the complete participation of parents in teacher-parent conferences, scheduled on the last Thursday of every school month (Musai & Boce, 2003). What makes these conferences unique in Albanian culture is that they are used by parents to both receive the necessary feedback about children's academic progress and provide support for teachers as they try to do their job (The World Bank, 2005).

METHOD AND INSTRUMENTS

Locations

Durres. The region of Durres was chosen for the study of Albanian high school students primarily because its schools are populated not only by the native families of this city, but also by children of families that a decade ago used to live all over Albania. In consultation with the regions' education authorities, a representative sample of high schools was selected. This sample included one of the city's most outstanding schools, two average schools in rural area of the city, and one school in the countryside. Of four chosen schools, three were comprehensive and one was vocational. The subjects included all Algebra 1 students present on the first and second hour period on the day each of the four schools were visited and included 219 students.

Grand Forks. The sample of American students was chosen from Grand Forks county, state of North Dakota, which is the researcher's living area. The data available from the National Assessment of Educational Progress (NAEP) indicates that ND appears to be among the top states for its high scores in mathematics of grade 8 (NCES, 2005). Located in the Northern Plains of the U.S. Grand Forks county is somewhat homogeneous in terms of population and economic status. Schools were selected in consultation with education authorities to represent the full range of the county's high schools.

All ninth graders in attendance of four schools visited during the first two hours of the test days were included in the sample. The total number of students included in the Grand Forks sample was 242. April and May 2007 were the periods of data collection in Grand Forks and Durres, respectively. Children in both countries begin compulsory education at age 6 so that there is no difference in age of students at the same grade level. In addition, the statistical data made available from the Ministry of Education in Albania indicates that 80 percent of eight graders enrolled in the academic year 2005-2006, continued to the upper secondary school. This percentage is similar to the enrollment rate of students in Grand Forks, given that not all ninth graders attend Algebra 1. Part of them is enrolled in faster or slower paths than Algebra 1 subject matter.

Measures

Instrument. The instrument consisted from a student questionnaire and an Algebra 1 achievement test. The student questionnaire was used to collect information about cultural practices in both countries. More specifically, the questionnaire included questions about teacher practices, use of textbooks, homework assignments, calculator usage, the school day organization, attitude towards school and learning, attitude towards mathematics and home environment (see Appendix A). Students' responses were measured in a 4-point scale. Only two questions related to "home environment" factor were measured in a dichotomous scale. Questions were analyzed to identify predictors of student scores on the algebra test.

A Texas publicly-released standardized test was administered to Algebra 1 students in four schools of Grand Forks and four schools of Durres (see Appendix B). The test was based on the careful analysis of the content of Algebra 1 (Mathematics 1.1, in Albania) and the respective syllabi. Mathematics teachers in each country checked each type of problem concerning its inclusion in the respective curricula. In the process of test design, attention was paid to selecting those items that fulfill the following conditions:

1. Items belong to the Algebra 1 content.
2. Items belong to the topics that are studied in all participating classrooms.
3. Items involve simple arithmetic computations with relatively small integers.

The test contained 15 problems. The first nine problems were multiple-choice questions and the last six problems were response-constructed questions. Students' answers on the 9 first questions were measured using 0-1 system: 0, for the wrong answer and 1, for the right answer. Students' responses on the last 6 questions were measured twice; they were checked for both the correct answer on 0-1 system and for the written representation approach on a 6-point scale. Thus, students' achievement was examined twice. The wrong-right system was used to assess the overall algebraic achievement, while the 6-point scale was used to measure the use of algebraic representations of solutions. Regardless of an answer being correct or not correct, the solution representation was measured as follows: 0-no solution at all, 1-use of arithmetic manipulations, 2-use of words or verbal representation, 3-use of charts, tables or any graphical representations, 4-use of language, such as algebraic symbols, equations, inequalities, and 5-use of combination of algebraic methods with other computational methods

Despite the frequent use of calculators, many teachers in Grand Forks and Durres do not allow their students to use calculators in test. Thus, some classes of both countries used calculators in this test and some did not. Because the test items did involve simple computations, the calculator usage was thought to have little impact on the overall performance.

Skilled, bilingual professionals translated the test and questionnaire from the original version in English into Albanian. The questionnaire and the test were included in the same booklet. Forty-five minutes were allowed for students of both countries to answer the questions of the questionnaire first, and then complete the test.

Initially, the instrument, first, was piloted in a class of the city of Grand Forks in order to check its reliability. The internal reliability of the test was high; Cronbach alpha coefficient for the test was .83. The Cronbach alpha for the items in the questionnaire ranged from .69 to .97.

RESULTS

Achievement test

The analysis showed that Albanian students in the overall test outperformed the American students; this difference was statistically significant at 0.05 level. The average score for the American students was 6.67 (SD = 2.99) and for the Albanian students it was 7.36 (SD = 3.19), [F (1, 459) = 5.7], p = 0.0173. The advantage of

Table1. The comparison of average scores on the overall achievement and algebraic skills

Country	Albania	US
Overall achievement	7,36	6,67
Representation skills	8,9	8,4

the Albanian students was also evident in the constructed response part of the test, which examined algebraic representation skills. In this domain the average score for American students was 8.4 (SD = 5.6), whereas for Albanian students it was 8.9 (SD = 7.5) (see Figure 1). But this difference, unlike the previous one, was not significant (p > 0.39)

Questionnaire

The perceptions of students in the two countries were compared in an attempt to clarify their possible relation to the Algebra 1 scores. Below is presented the instructional category, which included questions related to teacher practices, students' use of their textbooks and calculators.

Teacher practices. When students were asked about grading in front of the class, Albanian students responded with an average score of 1.8, whereas the average for American students was 1.1. [F (1, 462) = 98.9], p < .001. Lecturing from the board was scored higher from Albanian students. On a 4-point scale it was 2.5, whereas the American average score was 1.9. [F (1, 464) = 51], p < .001. Albanian teachers tend to ask for students' explanations and justifications more than American teachers do. Thus, the average score of Albanian students for this type of instruction was 2.5 whereas for American students it was 1.8. [F (1, 459) = 60.5], p < .001. More drastic was the difference of scores given by students when they were asked about beginning homework in class (see Table 1).

Use of textbooks. In Table 2 we see that not only Albanian students, compared with their American peers, are more dependable on their textbooks, but also that American students use relatively little their textbooks. The biggest difference in average scores is related to studying for exam. On the 4-point scale American students scored .96 whereas Albanian students 2.6 [F (1, 464) = 536.7], p < .001.

Use of calculators. Although some teachers involved in the study did not allow calculators during the test, students are always allowed or encouraged to use their calculators in mathematics classrooms. When students were asked about how much they use calculators in classroom, American students responded by an average score of 2.5, whereas Albanian students, 1.2, [F (1, 462) = 165, p < .001 Likewise, American students were more relied on their calculators. On a 4-point scale, they scored 1.7 as opposed to Albanian students who scored 1.2. [F (1, 462) = 44, $p < .001$.

Noninstructional factors included items related to school day organization, students' attitude toward school and mathematics, and home environment.

Organization of the school day. When students were asked to rate themselves in terms of spending a daytime in non-school related activities, in most of these activities American students gave themselves higher ratings than did the Albanian students. The respective average ratings for the U.S and Albanian students on *I watch TV, videos, use Internet or play with computer games* were 2.3 (SD=1.0) and 1.9 (0.9) [F (1,464)=18.9], $p < .001$. The item *I Read a book for enjoyment* was rated higher by Albanian students than by American students. In addition, Albanian students spent more time in preparing classes for the next day than did the American students, which is a clear indication that American students gave less emphasis to effort than did the Albanian students. Students of the two countries did not

Table 2. Teacher Practices

	AL (*N*=217)		US (*N*=242)		
	M	*SD*	*M*	*SD*	*F-value*
Our teacher grades solutions we present on the board	1,8	0,8	1,1	1	74
We explain or answer the question "why?"	2,4	0,7	1,8	0,9	60,5
We copy lecture notes from the board	2,5	0,7	1,9	1,1	0
We begin our homework in class	0,5	0,6	2,5	0,7	991

Note: All items are rated on a 4-point scale (see Appendix 2). df (1, 458-464). All Ps < .001

Table 3. Use of Textbooks

	AL (*N*=217)		US (*N*=242)		
	M	*SD*	*M*	*SD*	*F-value*
I use my textbook:					
To carefully read for understanding	2,6	0,6	1,2	0,9	342
To look at examples	1,9	0,9	1,6	0,9	9,8
To study for the exam	2,6	0,6	1	0,9	536,7

Note: All items are rated on a 4-point scale (see Table 1). df (1, 461-464). All Ps < .001

Table 4. Organization of school days

	AL (*N*=217)		US (*N*=242)		
	M	*SD*	*M*	*SD*	*F-value*
I watch TV, videos, use Internet or play with computer	1,9	0,9	2,3	1	18,9
I spend time with my friends	1,6	1	2,6	2,9	20,6
I work at a paid job	0,3	0,9	0,8	3	7,1
I play sports	1,1	0,9	1,8	1,3	42
I read a book for enjoyment	1,7	1	0,5	0,9	188
I prepare for all classes of the next day	3,5	0,8	0,8	0,6	1312
Tutoring out of your regular class	0,7	1,1	0,5	1,6	11,6

Table 5. Attitude toward Mathematics

	AL (*N*=217)		US (*N*=242)		
	M	*SD*	*M*	*SD*	*F-value*
I usually do well in mathematics	2,1	0,6	2	0,6	0,27
I enjoy learning mathematics	2,4	0,6	1,7	0,7	127
I need mathematics to learn other school subjects	2	0,8	2	0,6	0
I need to study hard in math to get into the university	2,6	0,7	2,2	0,6	22,7

Note: All items are rated on a 4-point scale (see Appendix 2). df (1, 458-464). All Ps < .001

Table 6. Attitude toward School

	AL (*N*=217)		US (*N*=242)		
	M	*SD*	*M*	*SD*	*F-value*
I like being in school	2,9	0,4	1,75	0,7	401
I think that the most important thing of going to school is learning new things	2,7	0,5	2	0,6	185
I think that most important thing of going to school is making new friends	1,4	0,7	1,9	0,7	59,7

Note: All items are rated on a 4-point scale (see Table 1). df (1, 461-464). All Ps <.001

Table 7. Factors that are significantly correlated with algebra achievement

	US	AL
I spend time with my friends	-0,16689 0,0093 242	-0,2045 0,0025 217
I play sports		-0,14486 0,0334 216
I prepare for all classes of the next day		0,24274 0,0003 218
I usually do well in mathematics	0,30931 0,0001 242	0,2442 0,0003 215
I enjoy learning mathematics	0,17296 0,007 242	
I need mathematics to learn other school subjects	0,22106 0,0005 242	
We copy lecture notes from the board	-0,16673 0,0094 242	
I need calculator to do math	-0,17447 0,0065 242	

differ in amount of time they devoted to tutoring (See Table 3).

Students' attitude toward mathematics. Albanian students expressed more satisfaction with learning algebra than did the American students. The average score of 2.4 for Albanian students was higher than the average score of 1.7 for American students [F (1,463) = 127], p < .001. In terms of satisfaction with performance in Algebra 1, Albanian and American scores did not differ significantly. The differences of scores were also not significant in the question that addressed the need of learning math in order to study other disciplines (see Table 4).

Attitude toward school. As it can be seen from Table 5, Albanians are more satisfied than Americans with being in school. Albanians' average score of 2.9 is higher than Americans' average score of 1.75. While being in school, Americans score higher the friendship aspect of school, whereas Albanians scored higher the aspect of learning new things.

Home environment. Students were asked whether they had at their homes a place designed for their study. On a two-point scale, American average score of .6 was lower than that of Albanian score of .9 [F (1,462) = 98.9], p < .001. The other question was related to parents concern about their children's success in school. In this case the difference of average scores was not significant and for both countries was high.

Relations between Students' Perceptions and Attitudes, and Achievement

One of the main purposes of the study was to find instructional and noninstructional factors that affect Algebra 1 achievement. After separating data for the

American and Albanian students, all possible correlations of variables within each sample were computed. Only significant correlations were sorted out and are presented in Table 7.

In the case of American students, of six significant correlations, only three variables had significant positive correlations with math achievement: *I Usually Do Well in Mathematics, I Enjoy Learning mathematics,* and *I Need Mathematics to Learn Other School Subjects*. The three other variables: *I Spend Time with my Friends, We Copy Lecture Notes from the Board,* and *I need Calculator to Do Math* had negative correlations with math achievement. For Albanian students, two variables, namely, *I Prepare for All Classes of the Next Day* and *I Usually Do Well in Mathematics* had positive significant correlation with the math achievement, whereas the two others, I *Spend time with my Friends* and *I Play Sports* were related negatively with achievement.

Two variables, *I Spend Time with my Friends* and *I usually do Well in Math*, were significant predictors for both samples. The most influential predictor for the American students *was I Usually Do Well in Mathematics* and for Albanian students it was *I Prepare for All Classes of the Next Day.*

DISCUSSION

The examination of students' performance on particular items of the achievement test shows that students of both countries have difficulties with learning algebra. On average they answered less than 50 percent of test questions correctly. Results related to the first item of the test (computing the value of an algebraic expression) show that approximately 35 percent of American students lack the skills needed to perform arithmetic operations with simple integers. On this item, many students chose the answers less than one, thus demonstrating the lack of basic estimation skills that would allow them to mentally distinguish between fractional values that are greater than 1 versus those that are less than 1. Likewise, results related to question 15 of the test (solving a linear inequality with absolute value) show that American classrooms are lack top students capable of correctly solving challenging problems.

Regarding the ability of students to use the algebraic language for solving response constructed problems nearly two thirds of ninth graders participating in this study demonstrated the use of nonalgebraic methods to solve algebra word problems. In addition, the majority of Albanian students, who are dictated by mathematics 1.1 curriculum to use only algebra for solving word problems, are not able to translate the relation part into an algebraic equation (taking for granted that this relational part has been identified from them). However, Albanian students, compared with their American peers, demonstrated more use of algebra.

Findings of this study show that instructional and noninstructional factors, expressed through students' perceptions, attitudes and beliefs, influence students' performance. Lower ratings given to blackboard-based lecturing are associated with low scores for American students. Likewise, high ratings given by American students to reliance on their calculators lead to lower test scores for them in Algebra 1 test. In contrast, the high rates given by Albanian students to such teaching practices as grading students at the blackboard or asking them to justify their answers, lead to higher test scores for them.

Noninstructional cultural factors appear to be also important in terms of affecting students' performance. This study, for example, underscores the consistence of the American students' self-concept of "doing well in mathematics" with their overall achievement. For Albanian students the need for studying hard to get into the universities lead to higher scores in the achievement test. In addition, Albanian math achievement was also predicted by their satisfaction with school and learning math.

Spending time for reading and learning is another factor that significantly influences students' achievement. When the after-school time is spent for playing and socializing with friends, a factor that is rated high by American students, then their achievement test scores tend to decrease; by contrast, when the time is spent for the academic preparation for the next day or reading in general, a factor that is rated high by Albanian students, then their test scores tend to increase. This conclusion for Albanian students is aligned with their beliefs that school is for learning, rather than for making new friends.

This study represents a first attempt of exploring differences and similarities between cultural factors in the U.S. and Albania that affect students' achievement in Algebra 1. More carefully designed comparative studies, involving bigger samples and especially qualitative methods, are needed to help deepen our understanding of how cultural factors exercised in both countries influence students' learning.

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APPENDICES

APPENDIX A
Student Questionnaire (English Version)

Part ONE: Questions intended to measure cultural factors
For each item mark one option only
I. Organization of the school days

1. On a normal school day, how much time (on average) do you spend before or after school doing each of these things?

a) I watch TV, videos, use Internet or play with computer games
___0 h; ___1 h; ___2 h; ___3 h; ___4 or more hours.

b) I spend time with my friends
___0 h; ___1 h; ___2 h; ___3 h; ___4 or more hours.

c) I work at a paid job
___0 h; ___1 h; ___2 h; ___3 h; ___4 or more hours.

d) I play sports
___0 h; ___1 h; ___2 h; ___3 h; ___4 or more hours.

e) I read a book for enjoyment
___0 h; ___1 h; ___2 h; ___3 h; ___4 or more hours.

f) I prepare for all classes of the next day?
___0 h; ___1 h; ___2 h; ___3 h; ___4 or more hours.

2. During this school year, how often have you had tutoring or extra lessons in Algebra 1 that are not part of your regular class?

______Every day or almost every day

______Once or twice a week

______Once or twice a month

______Sometimes

______Never or almost never

II. Students' attitude towards learning mathematics

3. How much do you agree with these statements about learning mathematics?
a) I usually do well in mathematics
___Strongly agree ____Agree ____Disagree ___Strongly disagree

b) I enjoy learning mathematics
___Strongly agree ____Agree ____Disagree ___Strongly disagree

c) I need mathematics to learn other school subjects
___Strongly agree ____Agree ____Disagree ___Strongly disagree

d) I need to study hard in math to get into the university or college of my choice
___Strongly agree ____Agree ____Disagree ___Strongly disagree

III. Students' attitude towards going to school

4. How much do you agree with these statements about the school

a) I like being in school
___Strongly agree ____Agree ____Disagree ___Strongly disagree

b) I think that the most important thing of going to school is learning new things.
___Strongly agree ____Agree ____Disagree ___Strongly disagree

c) I think that most important thing of going to school is making friends
___Strongly agree ____Agree ____Disagree ___Strongly disagree

IV. Home environment

5. In your home, is there a place designed for you to study?
______Yes ____No

6. Are your parents concerned about your success in school?
______Yes _____No

Part TWO: Questions intended to measure instructional factors

I. Teacher practices

1. Our teacher:
a) Grades solutions we present on the board
___Always or almost always ___Most times ___Some times ___Never or almost never

Reteaches the same topic on the next day when this topic is not understood by students:
___Always or almost always ___Most times ___Some times ___Never or almost never

How often do you do these things in class?

We explain or answer the question "why?"
___Always or almost always ___Most times ___Some times ___Never or almost never

We copy lecture notes from the board
___Always or almost always ___Most times ___Some times ___Never or almost never

We begin our homework in class
___Always or almost always ___Most times
___Some times ___Never or almost never

d) We have quiz

____Every day or almost every day

____Once or twice a week

____Once or twice a month

____Sometimes

____Never

3. How often do you take these types of tests?

a) We take multiple-choice tests
___Always or almost always ___Most times
___Some times ___Never or almost never

b) We take response question tests
___Always or almost always ___Most times
___Some times ___Never or almost never

c) We take a combination of the two above tests
___Always or almost always ___Most times
___Some times ___Never or almost never

II. Students' use of textbooks

4. I use my textbook

To carefully read for understanding
___Always or almost always ___Most times
___Some times ___Never or almost never

To look at examples
___Always or almost always ___Most times
___Some times ___Never or almost never

To study for the exam
___Always or almost always ___Most times
___Some times ___Never or almost never

III. Calculator usage

5. We use calculators during math classes
___Always or almost always ___Most times
___Some times ___Never or almost never

6. We are allowed to use calculators on tests
___Always or almost always ___Most times
___Some times ___Never or almost never

7. I need calculator to do math
___Always or almost always ___Most times
___Some times ___Never or almost never

APPENDIX B
The Standardized Achievement Test (English Version)

Part I: MULTIPLE-CHOICE QUESTIONS
Use the blank spaces surrounding the given questions or the backs of these sheets as a place for your scratch notes

Read each question. Then mark or circle the letter for the answer you have chosen.

1. What is the value of $y = \frac{x^8}{x^6}$ if x is 2?

$a)\ \frac{1}{8}$

$b)\ \frac{1}{6}$

$c)\ \frac{1}{4}$

$d)\ \frac{1}{2}$

$e)$ *None .of .the .above*

2. Which function includes all of the ordered pairs in the table?

x	-2	-1	0	1	2
y	9	3	1	3	9

$a)\ f(x) = x + 4$

$b)\ f(x) = x^2 + 1$

$c)\ f(x) = 2x^2 + 1$

$d)\ f(x) = -x^2 + 2$

$e)\ f(x) = -x + 3$

3. At which point does the graph of $f(x)=x^2+3x-18$ intersects the x-axis?

$a)(-9,0) and (2,0)$

$b)(-6,0) and (-3,0)$

$c)(-6,0) and (3,0)$

$d)(-3,0) and (6,0)$

$e)(-2,0) and (9,0)$

4. What is the value of x in the following equation?
3x-4(x+1)+10=0

$a)2$

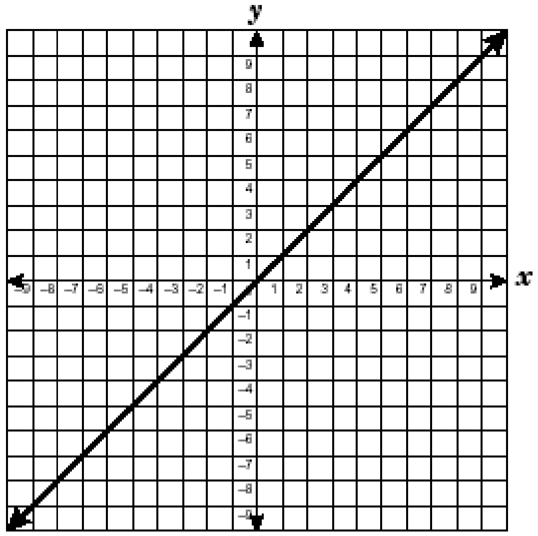
$b)6$

$c)10$

$d)11$

$e)14$

5. Which function is best represented by the graph below?



$a) y = \frac{1}{2}x - 1$

$b) y = -x$

$c) y = x^2$

$d) y = x$

$e) y = \frac{1}{2}x + 1$

6. Lola keeps a record of her weekly read pages. Last week she studied a total of 6 hours and read 51 pages. This week she studied a total of 9 hours and read 76.5 pages. Which equation can be used to find the amount of pages she would read at this rate if she studies x hours?

$a) y = \frac{2}{17}x$

$b) y = \frac{2}{3}x$

$c) y = 1.5x$

$d) y = 8.5x$

$e) y = 12.75x$

7. A portion of the graph of the function $y=2x^2-7$ is shown on the grid below. For which other value of x does y equal 1?

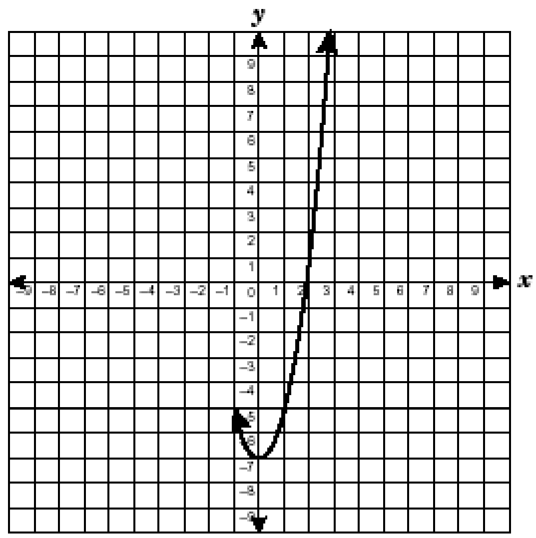
$a) -1$

$b) -2$

$c) -3$

$d) -4$

$e) -5$



8. Which equation represents the line that passes through the points (6, -1) and (-2, 3)?

$a) y = \frac{1}{2}x + 4$

$b) y = \frac{-1}{2}x + 2$

$c) y = \frac{1}{2}x - 2$

$d) y = 2x - 1$

$e) y = 2x - 11$

9. The height of a ball that was batted into the air at 160 feet per second is a function of t, the time in seconds after the ball was hit. The height is determined by subtracting 16 times the square of t from 160 times t. Which equation can be used to find t when the ball is 400 feet high?

$a) 160t - 16t^2 = 400$

$b) (160 - 16)t^2 = 400$

$c) 160(t^2 - t) = 400$

$d) 160 - (16 - t^2) = 400$

$e) 16t^2 - 160t = 400$

Part II: CONSTRUCTED RESPONSE QUESTIONS

In the following questions show all the steps that lead to your answer. Use the space below each problem to present your explanations

10. To convert a temperature in degrees Fahrenheit F, to a temperature in degrees Celsius C, the following formula can be used.

C= (5/9) (F-32)

What is the minimum value of F that will make C greater than or equal to 70?

11. Linda cut a 60-inch wire into 3 pieces. The longer piece was twice as long as each of the other 2 pieces, which

were the same length. What was the length of the longest piece of wire?

12. Yesterday, a total of 24 students were present in Alfred's class. There were 3 fewer girls than twice the number of boys. Find the number of girls and boys who were present in Alfred's class.

13. Ms. Ann has saved $325 for a new refrigerator. She plans to save an additional $50 per month. What is the least number of months she will need to save money in order to have enough to buy a refrigerator that costs $760, including tax.

14. Draw by hand a coordinate plane and shade the part that represents the graph of $2x-3y \leq 18$.

15. Solve the inequality: $|3x-5|+1 \geq 8$ and graph the solutions on the number line.

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Students' Perceptions of Sense of Community in Abstract Algebra: Contributing Factors and Benefits

Hortensia Soto-Johnson, Nissa Yestness, and Casey Dalton
University of Northern Colorado, Greeley, Colorado, USA

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In this phenomenological study, we explore how multiple assessments contribute to creating a sense of community (SOC) in an undergraduate abstract algebra course. Strike (2004) describes community as a process rather than a feeling and outlines four characteristics of community: coherence, cohesion, care, and contact. In this report, we describe contributing factors to and perceived benefits of SOC that students provided in an open-ended interview. Our findings indicate students viewed the teacher and the classroom environment as the primary sources for creating a SOC. Our findings also suggest students believed the SOC of the classroom increased classroom interaction and opened the doors of communication between students and with the instructor. The contributing factors align with Strike's and McMillan and Chavis'(1986) definitions of community, support social cognitive theory, and serve as a model for building a SOC in the classroom.

Keywords: Abstract Algebra, Multiple Assessments, Mathematics Classroom, Sense of Community

INTRODUCTION

In this qualitative study, we explore how multiple assessments contribute to creating a sense of community (SOC) in an undergraduate two-semester sequence abstract algebra course. Steen (1999) offers six guidelines to follow regarding undergraduate assessments in *Assessment Practices in Undergraduate Mathematics*. He claims assessment should (1) be a continuous cycle, (2) be an open process, (3) promote valid inferences, (4) employ multiple measures of performance, (5) measure what is worth learning, and (6) support every student's opportunity to learn important mathematics. With this in mind, mathematicians and mathematics educators began implementing a number of diverse assessments into their undergraduate mathematics courses including: collaborative assessments (Rouoviere, 1999), writing assignments (Blum, 1999), portfolios (Knoerr & McDonald, 1999), e-mail (Fried, 1999), and oral components through interviews or presentations (Heid, 1999). Although the literature pertaining to implementation of diverse assessments in undergraduate mathematics is plentiful, there is little research on the impact of various assessments implemented simultaneously into the same undergraduate mathematics course. In this report, we describe how multiple assessments meet other educational goals. Specifically we discuss how assessments contribute to the sense of community of the mathematics classroom. Our research questions are:

1. How do assessments contribute to a SOC in the mathematics classroom?
2. What are the benefits of creating a SOC in the mathematics classroom?

McMillan and Chavis (1986) define SOC as a perception where one feels (1) a sense of belonging, (2) influential, (3) nurtured, and (4) an emotional connection to the group. Hill (1996) suggests SOC goes beyond individual relationships and fluctuates from setting to setting, such as in a classroom. Strike (2004)

Correspondence to: Hortensia Soto-Johnson, PhD in Mathematics Education, School of Mathematical Sciences, University of Northern Colorado, Greeley, CO 80639, USA
E-mail: hortensia.soto@unco.edu

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further portrays community as a process rather than a feeling and outlines four characteristics of community: coherence, cohesion, care, and contact. Coherence refers to a shared vision; cohesion is the unity, which results from the shared vision; care is a necessity to initiate one into the vision, and contact refers to structural features of the community.

Much of the research related to SOC focuses primarily on adolescents (Pretty, Andrewes, & Collett, 1994; Sanchez, Colon, & Esparza, 2005; Strahan & Layell, 2006; Strike, 2004; Wighting, 2006). Pretty et al. argue SOC is significantly related to adolescent's loneliness. Sanchez et al. discuss the role of sense of belonging and academic outcomes of urban, Latino adolescents. Their results indicate a sense of school belonging is a good predictor for academic motivation, effort, and absenteeism. Strahan and Layell describe how struggling middle school students are able to progress in reading and mathematics under the tutelage of supportive teachers who provide an environment centered on the learner. Wighting shows how the use of computers in teaching may contribute to SOC and suggests SOC can be associated with academic success. Pretty and McCarthy (1991) ascertain the length of time a person spends in a setting and SOC do not have a consistent relationship. This suggests it is possible to create a SOC within a short- or long-term frame; our study supports this assertion.

More recently, researchers investigated the impact of SOC with college students, albeit the research is minimal. Jacobs and Dodd (2003) establish how burnout among undergraduate students can be predicted by factors such as social support, especially from friends. Students who feel a sense of nurturing from friends are less likely to experience burnout. Lounsbury and Loveland's (2003) research infers a psychological SOC is significantly related to extraversion, agreeableness, conscientiousness, and neuroticism in undergraduates enrolled in a lower-division psychology course. Thus, students who do not feel a SOC are less likely to interact with their peers. These results are crucial given collaborative work is the foundation of reform efforts (National Council of Teachers of Mathematics, 2000).

There is also research that addresses how graduate students build a community (Austin, 2002; Ferrer de Valero, 2001). Some of these inquiries focus specifically on mathematics graduate students (Carlson, 1999; Grevholm, Persson, & Wall, 2005; Herzig, 2002). Although the above-mentioned researchers do not use the term SOC, their results clearly indicate graduate students believe SOC is necessary for success in graduate programs. Austin describes the role of peer and faculty support in completing or continuing a graduate program. She also stresses the need for appropriate feedback and mentoring. Carlson characterizes good mentors as those who pose good questions, are non-intimidating, provide assistance in completing challenging problems, engage students in regular practice, and encourage students to discuss problems. Herzig emphasizes the importance of formal and informal interaction with faculty and the significance graduate students place on being viewed as junior colleagues. Research related to SOC and mathematics graduate students is scarce, and it is more limited at the undergraduate level. In this report, we add to the research knowledge of SOC in the undergraduate mathematics classroom.

Theoretical Perspective

This qualitative study is a phenomenological inquiry (Patton, 2002) because we explored students' lived experiences in a class with multiple assessments. Through the students' beliefs about, experiences with, and descriptions of the assessments, we uncovered how these assessments contributed to SOC. In an effort to implement assessments relevant to the literature and in line with Steen's (1999) criteria, we evaluated student's understanding of the content through homework, exams, oral interviews, projects, worksheets, and presentations. We attempted to promote valid inferences, allow for multiple measures of performance, measure what is worth learning, and support every student's opportunity to learn important mathematics through a variety of assessments. Social cognitive theory (Schunk, 2004) guided our implementation structure of the assessments since we believe social interaction influences what a student understands. This theory advocates the construction of knowledge, rules, skills, beliefs, and attitudes by observing others. The instructor made use of this theory by encouraging students to work together on all assessments except the exams. Since a majority of the students enrolled in the course were preservice secondary mathematics teachers, the course instructor valued the opportunity to model multiple assessments.

METHODOLOGY

The Course and Participants

The first-named author, who was the instructor of both courses, used the text *Abstract Algebra: A First Undergraduate Course*, by Hillman and Alexanderson (1994). The first semester centered on group theory and the second semester focused on rings and fields. Students successfully completed calculus I, II, and III, discrete mathematics, and linear algebra, before enrolling in the first semester course. Successful completion of the first course was a requirement for the second semester course. Eight male and twelve female students (N = 20) who completed the abstract algebra sequence participated in this study. The students were primarily preservice secondary teachers; three students intended to pursue graduate school.

Assessments Implemented

Below we provide a brief description of the assessments; a rich description of the assessments can be found in Soto-Johnson, Dalton and Yestness (in press). The teacher graded all assessments for correctness and clarity. Homework was assigned daily, collected and graded on a weekly basis, and returned the class period after it was collected. The instructor encouraged students to work together on homework and provided solutions to the required exercises in the hope students would assess their own work. Frequently, the distributed solutions encompassed student work, which allowed students to examine their peers' proofs.

The primary purpose of the exams was to assess students' mastery of the content in a timed setting. The exams included in-class, take-home, and oral interview components. The teacher did not permit students to work together on take-home components; this was one of the few assessments where the teacher prohibited collaboration. The oral assessments served as an opportunity for students to individually express their knowledge orally.

The instructor designed the projects to assist students with discovering abstract algebra ideas, connecting abstract algebra and the high school mathematics they will teach in the future, and studying abstract algebra applications. Worksheets served as a method to connect several complex abstract algebra concepts through in-class group work. In the second semester, presentations served as a channel for students to communicate mathematics orally and to learn presentation and proof techniques from one another.

Research Instruments and Data Analysis

Our data came from semi-structured, audio-taped interviews (Patton, 2002) with each of the 20 students (see Appendix I). It is important to note the SOC questions (Questions 15 and 16) came at the end of the interview, but some students volunteered the idea of community in the classroom earlier in the interview, (e.g. questions one and nine). In order to best capture and summarize the students' perceptions about contributing factors of SOC and perceived benefits, we employed a pattern, theme, and content analysis (Patton) of the transcribed interviews. Two researchers performed the transcribing, coding and theme searching. This contributed to the validity of the research and improved the quality of research since it allowed for open discussion of findings. Our analysis allowed us to identify the contributing factors and benefits of SOC as perceived by the students.

RESULTS

Through our analysis, we found students mentioned teacher and environment as the primary contributors to SOC. Figure 1 displays these categories and their subcategories. The subcategories for teacher include teacher characteristics and teacher imposed structure of the classroom including assessments. The environment subcategories consist of the classroom setting and the students enrolled in the course. Below we elaborate on the characteristics and use student quotes to support our claims. All names are pseudonyms.

Contributors to SOC

Teacher. Fifteen of the twenty students remarked how the teacher's social and receptive aspects contributed to creating a SOC. Students shared how the example set by the teacher, the teacher's caring personality, and her flexibility contributed to SOC. Sarah stresses the importance of the teacher setting expectations and modeling those expectations.

Sarah: I think it's not only the people that we have in there but the attitude that you set for us. Like you set the example and everybody follows, and then everybody becomes comfortable with the example you set.

The teacher-imposed structure of the classroom refers to how the teacher set up the class especially how she implemented classroom activities. Assessments primarily contributed to a SOC through group work, as acknowledged by 17 of the 20 students. One student mentioned how the difficulty of tests pushed him and other students to work together to study for the tests. This supports the importance of social support as described by Jacobs and Dodd (2003). The difficulty of homework also allowed for both peer interaction and student interaction with the teacher. Students specifically noted how the difficulty of the projects required collaboration. The mini-presentations, while not considered group work, also required student interaction in the classroom. Students, such as Agustin, reported feeling supported by one another and a sense of respect from peers during their presentations.

Agustin I definitely liked it as a presenter because I felt like I had to write something good because it was going to be in front of my class. …They were always really supportive. … They provided helpful comments.

Environment. Students perceived the classroom setting made up of tables in the first semester and a smaller class size as well as smaller classroom in the second semester contributed to SOC. These observations were commonly situated in a comment about growth of SOC from the first to the second semester, which eight students brought up during the interview. Half the students mentioned the two-semester sequence and common major as contributors to SOC. The fact the students were all mathematics majors is an example of coherence as described by Strike (2004); it translates, at least in this classroom, to a shared vision. The following statement by Melissa refers to the shared vision described by McMillan and Chavis (1986).

Melissa: Our class, I feel like we always run into each other. We're also all math majors, so most likely we've had other classes with each other. So with that, we can use each other as resources. I think that that's a huge part of our community, because we all have something in common.

Other students described an existing feeling of cohesion resulting from the SOC created in the first semester. Although Pretty and McCarthy's (1991) research suggests the length of time a person spends in a setting does not influence SOC, our students believe otherwise. It appears coherence and a sense of belonging to this classroom began in the first semester course and was strengthened in the second semester (Strike, 2004; McMillian & Chavis 1986). For some students, such as Bruno, the challenging assessments contributed to creating a SOC.

Bruno: For a lot of people it is the first time they are struggling in math and so if other people are also struggling in math it just automatically builds camaraderie.

Bruno's comment supports the literature (Jacobs & Dodd, 2003) related to SOC in graduate school; challenging assignments bring students together, to collaborate on the assignment. The assessments were designed to be challenging and required collaboration.

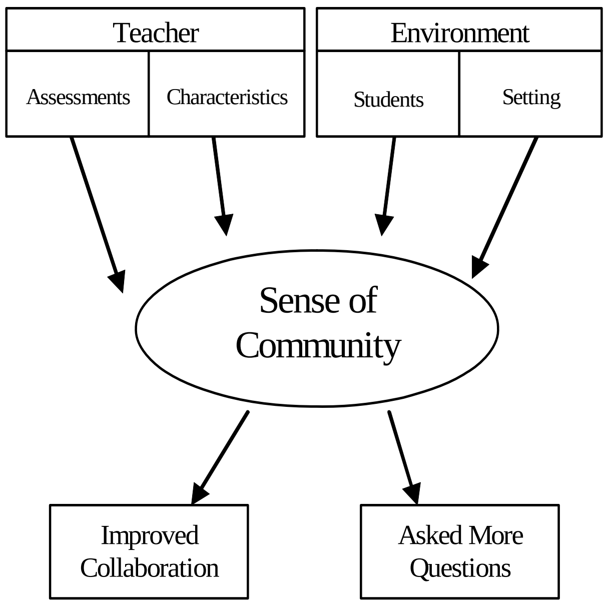

Figure 1. Benefits of SOC

Benefits of SOC

We expanded our SOC model, which only included contributing factors to include benefits of SOC as shown in the bottom portion of Figure 1. Through the coding process, we unveiled two important benefits of SOC as perceived by the students. Students believed a SOC improved collaboration and created an atmosphere where students felt comfortable asking questions. These benefits stem from an environment that endorses learning through increased comfort level among the students and between the students and the professor as illustrated by George.

George: We are totally different people and never would have become friends or associate if it wasn't for classes… The whole class, we can all discuss and ask each other question. It's a comfortable atmosphere.

Students reported they were more prone to ask questions in class and work with other students both in and out of class compared to other math classes.

Jayden: I think there was a group dynamic. I got to the point where I could even ask people that I wouldn't have talked to before how to solve a problem or work through things.

More importantly, the students described how SOC helped their learning. Students felt their grades reflected their involvement in the classroom community. For example, Melissa comments on how her lack of involvement in the community the second semester affected her grade and her confidence to work with the material.

Melissa: When we work outside of your office, I don't have time to do that anymore. People I used to converse with, I don't really talk to as much anymore. So it's a little different this semester. I think it has impacted my learning. Feeling not necessarily as big a part of the community as I was. I think it's made me less confident in the class, and with that obviously my grades are not nearly as good as they were last semester.

DISCUSSION

The model's two main categories emerged from the original research question regarding how assessment contributed to the SOC in the classroom. We broadened the assessments category to include teacher characteristics and named it Teacher since the teacher is responsible for the assessments. We also found students credited their physical setting as well as each other as contributors to the SOC. However, by studying the model it is evident both the teacher and environment categories have a human aspect, the teacher and the students. Studying the model through this lens helps us situate our results within the literature; see Table 1 below. The two subcategories, teacher characteristics

Table 1. Results Related to Literature

Research Results	Category: Teacher Subcategory: Characteristics	Category: Environment Subcategory: Students	Category: Teacher Subcategory: Assessments	Category: Environment Subcategory: Setting
Literature	Coherence – shared vision (Strike) Care – necessity to initiate once into the shared vision (Strike) Feels a sense of belonging (McMillan and Chavis) Feels influential (McMillan and Chavis) Feels nurtured (McMillan and Chavis)		Contact – structural features of community (Strike)	

(from teacher) and students (from environment), align with care and coherence from Strike (2004) as well as feeling a sense of belonging, nurturing and influential from McMillan and Chavis (1986). The assessments and setting subcategories from teacher and environment align more closely with contact from Strike.

Studying our model in relation to the literature indicates we can extend the human and environment aspects to Bandura's model of social cognitive theory. Bandura describes his model as "Human functioning is explained in terms of a model of triadic reciprocity in which behavior, cognitive and other personal factors and environmental events all operate as interacting determinants of each other" (as cited in Schunk 2004, p.84). The environment node includes the classroom setting as well as similarities among the student. Further, the teacher can constitute part of the environment because of the manner in which she implemented activities. Thus, the environment is composed of students, teachers and physical attributes of the classroom. Both the teacher and the students represent the behavior and the personal components of Bandura's model.

Furthermore, the teacher's behavior or the example she sets impacts how students interact with one another and creates an environment conducive for questions to the teacher and to other students. Thus, her behavior motivates the personal category as described by Carlson (1999). The teacher's personal qualities (or characteristics) influence the behavior in the classroom as described by students. Similarly, the students' behavior can sway the teacher's behavior. When students ask questions and engage in classroom activities the teacher may reflect on this and stimulate positive energy in the classroom. The students' personal interactions influence the behavior of the teacher and that of the entire classroom.

The results suggest creating a SOC in the classroom and the factors contributing to the SOC have some classroom implications. Our model and student comments illustrate transferable components as well as other components a teacher of any course can replicate. Some of the contributors such as teacher and student characteristics are not transferable. On the other hand, contributors such as teacher-imposed structure of the classroom and classroom setting are easily transferable into the classroom. The variety of assessments and their challenging nature provide a setting in which a class can experience a SOC.

Some students commented how the difficulty of some assignments influenced them to work with other people when in previous classes they worked by themselves because they did not feel the need to collaborate with other students. Multiple group assignments provided the opportunity for students to work with one another. Students referenced the emphasis on group work in the classroom and group assignments as a major contributor to the building of SOC. Other transferable contributors include environmental factors such as tables, small class size, small classroom, and a yearlong two-semester sequence.

We found facilitating a course that promotes interaction creates a SOC. Engaging students inside and outside the classroom through challenging assignments can enhance this learning perspective. We encouraged this collaboration outside the classroom with challenging assignments with the intention that students would seek the support of their classmates and collaborate outside the classroom. Miguel describes this for us from the perspective of a student.

Miguel: Especially because it's gone on all year. We've all taken this really, really hard class, or at least everyone says it's really hard, but maybe it's not that bad. We all had a chance to work with each other on at least something. I've worked with nearly everybody. It's a good community.

Limitations and Implications for Future Research

One limitation of this investigation is the instructor is the primary researcher and interviewer, thus the research lacked anonymity. Although this can influence students to say what they believe the instructor wants to hear, the students did not hesitate to state pros and cons of the assessments. We also acknowledge that our data sources are limited, but our data is rich in description.

We have seen an increased amount of classroom collaboration in mathematics classrooms since the beginning of calculus reform. Many researchers have demonstrated how collaboration assists with learning mathematics. Social cognitive theory (Schunk, 2004) certainly champions this belief. However, we are not aware of the full impact of collaboration on other educational goals. Our students' perceptions demonstrate multiple assessments, which require collaboration can contribute to building a SOC, which is important to learning.

More research is needed to validate the findings of this study as well as to continue to discover and document benefits of collaborative work and alternative assessments. It is clear that in this course, the collaboration was effective and students learned not only from the teacher but also from one another. The impact of effective facilitation of collaborative work is of great value. This research can be expanded by investigating the influence that courses with multiple assessments have on pre-service teachers. Specifically, how do these courses impact their teaching and assessment styles?

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Appendix

Interview Questions

1. Did you learn from the presentations? Why or why not? Discuss from the standpoint of a presenter and evaluator.
2. Did you learn from the projects? Discuss in terms of the presentations and presenting?
3. What were the advantages of working on a project as a exam?
4. What were the disadvantages of working on a project as a exam?
5. Do you feel that it was valuable to try to read mathematics on your own as part of the exam #3 project? Why or why not?
6. What assessments do you feel reflected your knowledge of the material best? Why?
7. What assessments do you feel do not reflect your knowledge of abstract algebra? Why do you feel this way?
8. What assessments did you feel were the most challenging? Why?
9. What assessments did you enjoy the most? Why?
10. Did you enjoy having a practice midterm oral? Why or why not?
11. How do you feel about having an oral component to the final? Explain.
12. Have your feeling towards the oral component changed from last semester? If so, how? If not, why not?
13. Do you feel that your proof –writing skills have improved over the last two semesters? What do you attribute this too?
14. Is there anything that you would like to share with me about the assessments that have been used in the abstract algebra class?
15. Did you feel that there was a sense of community during this and last semester? Why or why not?
16. What do you feel contributed to this?

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Constructivism and Peer Collaboration in Elementary Mathematics Education: The Connection to Epistemology

Anoop Gupta
University of Windsor, Windsor, CANADA

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In this paper, an attempt is made to determine if peer collaboration increases student achievement in teaching elementary mathematics. Empirical evidence and philosophical problems with constructivist epistemology are considered. Two things are argued: first, it is reasonable to think, for elementary mathematics, peers collaboration is useful (especially in heterogeneous groups). Peer collaboration is an appendage to instruction, not a replacement for the didactics of an expert, or individual problem solving (which occurs both at its inception, when mathematics is discovered as well as advanced levels). There is reciprocity between individual and social settings in learning mathematics. Second, for the teaching of mathematics an adequate epistemology will guide, to some extent, a successful pedagogy.

Keywords: Constructivism, Peer Collaboration, Mathematics Education

INTRODUCTION

Pedagogical constructivism entails three principles: *encouraging collaboration*, primitive activity and exploration, respecting multiple points of view and emphasizing authentic problem solving (Solomon, 2000, p. 328). Pedagogical constructivism (henceforth "constructivism") is also sometimes taken to be a full blown philosophical position about the nature of knowledge; namely, we make knowledge up like the rules of chess. I argue that the value of peer collaboration is contingent upon the context and limited by our epistemological stand in specific ways that is little noticed by constructivists.

I proceed by first considering the conditions under which peer collaboration in mathematics is appropriate. Second, I consider the claim that in order make constructivism generally plausible, we must separate epistemological and pedagogical variants. Finally, I argue however, that employing peer collaboration in mathematics must be determined in relation to the student, teacher, nature of the subject matter, and is likely to be guided by our epistemological stance.

Peer collaboration could be studied independently of constructivism. Considering peer collaboration and constructivism together is justified: to jettison peer collaboration requires revising constructivism. It is reasonable to think that the debate over peer collaboration in mathematics must be resolved by empirical studies, however (Fawcett & Gourton, 2005). I am not conducting an empirical study, and, rather, offer a philosophical comment on the debate over constructivism and peer collaboration. Further, I shall use examples from science and advanced mathematics because the sources I use do so. Finally, when I discern the relationship of our epistemology to our pedagogy (Figure 1), some possible adherents of several views related to them are inferred for the purpose of illustration alone. Scholars of individual thinkers referred to may attempt to amend their place in the picture I sketch, which would yield debates that will transcend the purpose of this paper.

Correspondence to: Anoop Gupta, PhD in Mathematics Education, Faculty of Education, University of Windsor, Windsor ON N9B 3P4, CANADA
E-mail: akgupta03@yahoo.ca

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Peer Collaboration

According to Fosnot, Professor of Education, Director of Mathematics in the City, New York, and Dolk, researcher at the a the Freudenthal Institute in the Netherlands, mathematics is either about transmitting knowledge (didactic learning) or constructing meaning, but not both (Fosnot & Dolk, 2005). Fosnot, also editor of *Constructivism, Theory, Perspectives, and Practice,* offers the following definition:

Constructivism is a theory about *knowledge and learning*. It describes knowledge not as truths to be transmitted or discovered, but as emergent, developmental, nonobjective, viable constructed explanations by humans engaged in meaning making in cultural and social communities of discourse. Learning from this perspective is viewed as a self-regulatory process of struggling with the conflict between existing personal models of the world and discrepant new insights constructing new representations and models of reality as a human meaning-making venture…([Emphaisis mine]. Fosnot, 2005, p. ix)

Fosnot concluded, "Major restructuring is needed in the schools if we are to take constructivism seriously" (Fosnot, 2005, p. xi). Philips, editor of a volume published by the National Society for the Study of Education, dedicated to the theory, remarked, "Constructivism is currently a fashionable magic word in the Western intellectual firmament… (Philips, 2000a, p. 1). Ernest von Glaserfeld, the first social constructivist, puts it this way:

The key idea that sets constructivism apart from other theories of cognition was launched about 60 years ago by Jean Piaget. It was the idea that what we call knowledge does not and cannot have the purpose of producing representations of an independent reality…(Glaserfeld, 2005, p. 3)

Putting aside the constructivist appropriation to Piaget, it is at least clear many have tried to develop it in relation to Vygotsky in order to emphasize peer collaboration. Pichat and Ricco (2001), psychologists at the University Paris 8, noted that there are three poles in the classroom: the student, teacher and knowledge. For Vygotsky, upon whom they rely, cognitive mediation (contractual expectations) is the main factor in understanding (Piachat & Ricco, 2001). Mastery of mathematics, according to Pichat and Graciel, is more than knowledge of procedures, but knowing when to employ them, which requires the guidance of the teacher in the Vygotskian zone of proximal development (ZPD).

In "Small-group Searches for Mathematical Proofs and Individual Reconstructions of Mathematical Concepts", Vidakovick and Martin agreed that constructivist theory provides the basis for co-operative and collaborative learning (Vidakovic & Martin, 2004). Discussion, they claimed, leads to deeper understanding.

According to Vidakovick and Martin, we internalize culture and externalize it by passing it on. By missing an opportunity for externalization, we limit internalization; that is to say, if we do not have a chance to explain our thought to someone else we fail to solidify learning (Vidakovic & Martin, 2004). They emphasized that in the mid-20th century two theories have dominated mathematics education research, Piaget's information processing model and Vygosky's social-constructivism. Vidakovic and Martin advocated co-constructivism that reconciles both the individual and social aspects of Piaget and Vygotsky (Vidakovic & Martin, 2004). Viadaok and Martin concluded that mathematics learning can be enhanced by peer-collaboration in small groups, provided there are some common understandings of what counts as a proof.

Lillian M. Fawcett and Alison F. Gourton, in "The Effects of Peer Collaboration on Children's Problem-Solving Ability", pointed out that group work, according to constructivists, enhances learning through participation, makes transition to the wider community easier, and maximizes use of limited resources (Fawcett & Gourton, 2005). For Vygotsky cognitive change is linked to collaborative interaction. For Piaget, learning results from peer interaction, which provides conflict: cognitive development depends on a conflict between what is known and not, creating disequilibrium (Fawcett & Gourton, 2005). For Vygotsky, the notion of a community of learners supports the idea of group work (Fawcett & Gourton, 2005).

According to Fawcett and Gourton, peer collaboration increases student achievement, though depends on complex factors like age, ability level, partners, motivation, confidence, gender and task. Further, there are more cognitive benefits when participants listened and reflected on logical consistency and precision (Fawcett & Gourton, 2005).

There must be exposure to a higher level of reasoning, active participation (active reasoning and the exchange of ideas), and communication (Fawcett & Gourton, 2005; Vidakovic & Martin, 2004). Different skill levels lead to the conflict necessary for conflict (in ZPD and for Piaget). Active participation and verbal interaction are necessary for internal reorganization, as well as cognitive change.

Philosophical Quandaries

Philosophical problems with constructivism clarify what would make peer collaboration desirable, and we can begin with the critics. Sriraman, in a recent article in *Mathematical Behavior*, has pointed out that deduction or induction from particular cases (i.e., generalizing activity) requires working over an extended period of time (Sriraman, 2004). Slezak (2000), director of the program in cognitive science at New South Wales, worried, "On these [constructivist] views education becomes indoctrination, pedagogy is propaganda, and ideas are merely conventional conformity to social consensus" (p. 93). Constructivism leads to relativism, which is at its "heart" (Slezak, 2000, p. 93).

Matthews (2000), in "Appraising Constructivism in Science and Mathematics Education", agreed with Fosnot, for instance, that constructivism is not just a theory about learning but also "our culture's greatest and most enduring achievement, namely science" (p. 162). Constructivism, as Matthews pointed out, could also be a theory of cognition, learning, teaching, education, personal knowledge, scientific knowledge, educational ethics, politics, and a worldview (Matthews, 2000, p. 163). According to him, the semantic and epistemological domains are often confused.

Matthews disagreed that constructivism must entail idealism (Matthews, 2000, p. 163). Social constructivism, as held by Glaserfled, leads to paradoxes, like that of self-refutation (i.e., the theory itself is constructed) (Matthews, 2000, p. 167). Matthews separated educational, philosophical, and sociological constructivism.

Matthews wrote, "Language, especially scientific and mathematical language needs to be mastered and, at the end of the day, transmitted" (Matthews, 2000, p. 171). Definitions need to be taught, and are not always made up by learners:

One might reasonably ask, at this point, whether learning theory

or ideology, is simply getting in the way of good teaching. Why must learners construct for themselves ideas of potential energy, mutation, linear inertia, photosynthesis, valiancy and so on? (Matthews, 2000, p. 180)

Several commentators suggested separating epistemological issues from pedagogical ones (Matthews, 2000; Burbules, 2000). Burbules (2000), in "Bridging the Impasse", wrote, "Focus on trying to understand the practices and procedures by which constructions come to be created, adjudicated and commonly shared" (Burbules, 2000, p. 326).

Burbules concluded that teachers need different tools, and that constructivism may be one of them (Burbules, 2000). Constructivism, after all, has the virtue of attempting to produce the kinds of conditions that drive scientific [and mathematic] exploration in the first place (Burbules, 2000; Ball & Bass, 2000). If peer collaboration in mathematics has value, it will be because pedagogy requires and accepts it.

The Reciprocity between Practice and Epistemology

When longitudinal studies are wanting, ethnographic ones intimate a solution. James W. Stigler and Harold W. Stevenson, who have conducted ethnographic studies of mathematic education, attempted to explain the "startling" higher achievement of Asian students in mathematics, compared to their American counterparts (Stigler & Stevenson 1999, 66). Stigler and Stevenson claim that the Asian class is "constructivist", yet also involves *less peer collaboration and more instructional time with the teacher* (Stigler & Stevenson, 1999, pp. 69, 71). Stigler and Stevenson contend that we need to question if individualized or group learning is better than whole-class instruction (Stigler & Stevenson, 1999).

The value of peer-collaboration can only be determined perhaps for a specific subject, class, and lesson. To be sure, the fruitfulness of peer collaboration will also depend on the teacher and culture of the students.

Looking at matters from a neurological perspective, Kong and associates, publishing in *Cognitive Brain Research*, have showed that the parts of the brain used to carry out addition operations are also used for subtraction, which is useful in breaking the stranglehold between pro- and anti-constructivists. Kong and associates conjectured:

Children usually start learning arithmetic with simple addition, then subtraction. They later learn the more complicated aspects of addition and subtraction like carrying. This developing order may be reflected in the neural circuitry of mental calculation and may explain why the neural network of simple addition is the basis of other calculation types. (Kong et al., 2005, p. 407)

In mathematics we move from simplicity to complexity, reflecting the nature of the subject matter.

Furthermore, the factory model of education is the setting in which constructivists implement peer collaboration. Long before populations were committed to mass education, we learned in a master-disciple relationship. The apprenticeship system was universal: the blacksmith, carpenter, musician and mathematician, trained the apprentice. In the apprenticeship system, collaboration is between someone who has vast experience with solving problems in the given field.

An important point is revealed about peer collaboration from the apprenticeship system: it is useful when one of the participants is knowledgeable enough to guide others. Also, it is still reasonable to think that peer collaboration is generally useful.

Confirming previous work, Schliemann and Carraher (2002), in "The Evolution of Mathematical Reasoning: Everyday versus Idealized Understandings" noted that mathematics involves personal discovery, as well as conventional symbols and contexts (Schiemann & Carraher, 2002, p. 242).

Mathematics relies upon specific representations and tools, which play a role in the structure and role of mathematical thinking (Schiemann & Carraher, 2002, p. 244). Constructivists, they emphasized, must realize that some notions are more useful in the long run (even if at odds with individual ways of doing things). "17 – 6 = 11" is more useful that working with a fish bowl (Schiemann & Carraher, 2002).

We can distinguish between the common and deep contexts. The *common context* is grade 5, mathematics students, at Coronation Public School, in Windsor, Ontario, Canada. There is also the *deep context* (or culture) which includes previous experiences and assumptions of the class. We return to complexity: in the relationship between the student, teacher, and subject matter, there is a balance to be had. To resolve the debate, I propose we consider both philosophical foundations of peer collaboration and the implications for pedagogical practice.

Epistemology and Group Work

Philosophers since at least Frege (1884/1953) have scrutinized the relationship between what has come to be known as the *context of discovery* from that of the *context of justification.* We may wish to recall that Frege separated how we discover something from how we justify it. Yet considering group work in elementary mathematics prompts us to add the *context of learning.* We can distinguish, in different ways that have been held by various scholars, between how knowledge is discovered (e.g., when it first was discovered), justified (e.g., proved), and learned (i.e., how we teach *accepted* knowledge). The following chart (table 1) depicts the relations between the three contexts of discovery, justification, and learning.

Table 1. Some relations of the contexts of discovery, justification, and learning (explained in detail below).

View	Context of Discovery	Context of Justification	Context of Learning
Metaphysical realist-1	+	-	+
Metaphysical realist-2	+	-	-
Naturalist-1	+	+	+
Naturalist-2	+	+	-
Skeptic	-	-	-
Radical Constructivist-1	-	+	+
Radical Constructivist-2	-	+	-

For metaphysical realists the contexts of discover and justification must be separated, in principle, yet there is disagreement about the consequences for learning. For the metaphysical realist-1, there is knowledge to be discovered that we may never reach and learning is modeled on practices of inquiry in the relevant field. For the metaphysical realist-2, like Frege, there is knowledge to be discovered that we may never obtain and learning need not be modeled on current practices in the relevant field.

As is well known, naturalists blur Frege's distinction: how knowledge is acquired is how it must be justified. Yet, like metaphysical realists, may disagree with the consequences for pedagogical practice. The naturalist-1 holds that their epistemology provides the ground of a pedagogical practice. Conversely, the naturalist-2 agrees with Frege only in this: our epistemology need not reflect our pedagogy.

The global skeptic suspends judgment about the possibility of knowledge, its justification, and it is reasonable to think, must make learning an arbitrary matter: there cannot be any science of teaching anymore than anything else. At best, we can obtain solidarity.

Philosophical constructivists attempted to avoid skepticism by rejecting the recognition transcendence of truth and by inextricably tying it to our methods of justification. The radical constructivist-1, like von Glasserfeld, denied that knowledge is mind-independent: all truth is constructed within modes of justification. The radical constructivist-1 holds that knowledge should be taught the way we justify it. The radical constructivist-2, like it is reasonable to conjecture, Hilbert formalist thought of the 1920s, are not wedded to a pedagogy modeled on the way knowledge is produced.

It is apparent from the two species of metaphysical realism, naturalism, and radical constructivism discussed that whatever view we have of knowledge does not entail a pedagogical program. At the same time, it is reasonable to think that the first species of metaphysical realism, naturalism, and the radical constructivist, where there is some connection between the contexts of discovery or justification and learning could be the basis of compelling arguments in that direction. That is, if the naturalist-1 is right we would have one reason to teach in a way that models how we actually discover and justify knowledge, as much as is feasible. If the radical constructivist-1 is right, we would have a reason to emphasize mathematics as a social game where we attempt to master the rules of symbol manipulation.

Without straying too much further into epistemological debates, suffice it to say that the realist has an edge: mathematical truth is eternal and unchanging, guiding even constructivist pedagogy. We are directed in terms of content: there is one and only one mathematics. Conventional notation and methods, further, are guided by both biology and mathematics. "159 – 7 = 152" is easier to solve than "CLix – vii = CLii", which is why in fact we use Arabic numerals not Roman ones. Some cultures do not count numbers greater than identified body parts. A number system, like our Arabic-Indian one (the ten base number system with a "0"), is necessary for calculations involving high cardinalities, since we first need to conceive of those numbers (or have a procedure for constructing them). In mathematics, social constructions are circumscribed.

Practice and Group Work

We can consider the implications for practice by reflecting on the suggestions of constructivists emphasis upon group work, which is consistent with their epistemological assumptions about the social nature of knowledge. Nelson (1996), a biology professor at Indiana University who has won awards for excellence in teaching, outlined what he dubbed "the myths of rigor" in traditional pedagogy (e.g., tough courses, thwarting grade inflation, lecturing, focusing on content, emphasizing student responsibility, and handing in work on time). He argued, however, that didactic pedagogy favors the upper-middle class and supports discrimination against non-traditional students.

Nelson, reviewing the relevant literature, noted that those from upper middle class backgrounds automatically formed collaborative groups to get through calculus, increasing their "status" for helping others, whereas underprivileged children think that "only weak students study together" (1996, p. 166). He observed from studies and his experience that modifying traditional pedagogy with active learning, discussion, and peer collaboration, benefits all students and the weakest segments of the population the most.

Nelson concluded that traditional didactic ways of teaching are comparatively ineffective and bias. He contended that the reason faculty members continue with ineffective teaching practices is self-serving, relies upon erroneous attribution schemes (blame the victim), and dysfunctional illusions of rigor.

It is altogether reasonable to think that we learn best when we have to interact and communicate with others. Building upon the social dimensions of learning will increase student achievement, by boosting interrelated factors, such as meta-cognition, memory retention, motivation, and the understanding that comes with having to explain what we think to others. It is a platitude but worth reciting: we are social creatures.

One reason group work is sometimes effective is because it increases motivation. We are more motivated to excel in a discipline when it is considered a value, culturally or in our interpersonal groups, which we internalize. Group work can change the value of mathematics for disadvantaged groups (where mathematics has little value), for both constructivist and naturalist theorists (e.g., behaviorists).

Prospects for Group Work

Group work, in fact, functions as part of a carefully considered pedagogical strategy, which though not entailed, may be at the very least consistent with our overall philosophical view of knowledge. I argued two things: first, for mathematics, it is reasonable to think, peer collaboration is an appendage to instruction, not a replacement for the didactics of an expert or individual problem solving. I can only conjecture that peer collaboration is useful at the elementary as well as some advanced settings (in heterogeneous groups that facilitate instruction). There is a knowledge we need to transmit. In addition, if we are to follow the system of apprenticeship, mathematics is done individually or in dyads (insofar as we spend time practicing), both at its inception, when discoveries are made, and at advanced levels. A great deal of practice is required to develop the skills and the appropriate neural networks, to excel in any discipline. At least some of the practice must be done alone, which is consistent with what we know of those who have excelled, across disciplines. Though pedagogy cannot, it is reasonable to think, cannot fully mimic the way knowledge is discovered, it is desirable to move in that direction because it is more likely to produce an authentic context for learning.

In fact second, for the teaching of mathematics an adequate epistemology can usefully reflect a successful pedagogy, its principles, which take into account the student, teacher, and subject matter. Pedagogy, at the very least, must reflect the fact that epistemic discoveries are made by individuals that rely upon a social store of previously accumulated knowledge. There is reciprocity between individual and social settings in learning mathematics. The pedagogue must keep the entire repertoire of heuristics at her disposal, both what follows her assumed epistemology and what departs from it.

Some constructivists, however, not only reject all dialectic methods but do not realize when they rely upon rote learning, a reward system, and independent study. My aim has not been to argue that peer collaboration has no place, but rather to critically reflect on how we adjudge its worth. Our epistemology is one landmark in guiding our choice of heuristic. It is important to keep in mind, however, that both naturalist and constructivist epistemologists can embrace the same pedagogy of active learning where group work is prominent. Group work has a place and does not entail a knockdown argument against naturalists. On the contrary, naturalists need to detail the implications of their epistemological stand is for scholarship of teaching and learning.

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The Effects of Inquiry-Based Computer Simulation with Cooperative Learning on Scientific Thinking and Conceptual Understanding of Gas Laws

Sopiah Abdullah
Gaya Teacher Training Institute, Sabah, MALAYSIA

Adilah Shariff
Universiti Sains Malaysia, Penang, MALAYSIA

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The purpose of the study was to investigate the effects of inquiry-based computer simulation with heterogeneous-ability cooperative learning (HACL) and inquiry-based computer simulation with friendship cooperative learning (FCL) on (a) scientific reasoning (SR) and (b) conceptual understanding (CU) among Form Four students in Malaysian Smart Schools. The study further investigated the effects of the HACL and FCL methods on performance in scientific reasoning and conceptual understanding among students of two reasoning ability levels, namely empirical-inductive (EI) and hypothetical-deductive (HD). A quasi-experimental method that employed the 3 x 2 Factorial Design was applied in the study. The sample consisted of 301 Form Four students from 12 pure science classes in four Smart Schools which were all randomly selected and assigned to treatment (HACL & FCL) and control (TG) groups. The results showed that students in the HACL group significantly outperformed their counterparts in the FCL group who, in turn, significantly outperformed their counterparts in the TG group in scientific thinking and conceptual understanding. The findings of this study suggest that the inquiry-based computer simulation with heterogeneous-ability cooperative learning method is effective in enhancing scientific reasoning and conceptual understanding for students of all reasoning abilities, and for maximum effectiveness, cooperative learning groups should be composed of students of heterogeneous abilities.

Keywords: Science Education, Biotechnology, Attitudes, University Students.

INTRODUCTION

The development of thinking ability in individuals has always been recognized to be of great importance to enable them to make decisions wisely and to solve a problem efficiently. Acclaiming the importance of the development of thinking ability in students, Malaysian Curriculum Development Centre introduced thinking skills as one of the major skills to be inculcated in the Secondary School Revised Science Curriculum that was implemented in 2003 (KPM, 2002, p.20). Thinking skills refer to a set of mental capabilities or patterns of thought which are rational or logical in nature. For the purpose of this study, thinking skills also include scientific thinking or higher reasoning abilities that involve what Piaget has termed formal operational thought (Piaget, 1964), or renamed by Lawson (1995) as

Correspondence to: Sopiah Abdullah, Science Department, Gaya Teacher Training Institute, 88805, Kota Kinabalu, Sabah. MALAYSIA
E-mail: snyetmoi@yahoo.com

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hypothetical-deductive (HD) thinking patterns which include identifying and controlling of variables, proportional thinking, probabilistic thinking, combinatorial thinking and correlational thinking. Mastery of scientific thinking skills is one of the aspects given emphasis in the Smart Schools science curriculum (Poh, 2003). The Smart Schools were introduced in 1999 by the Government with the objectives of promoting a knowledge-based culture as well as producing caring students with critical and creative thinking skills (Multimedia Development Corporation, 2000).

Physics is a field that involves the study of physical phenomena, and students are continuously required to identify the hidden concepts, define adequate quantities and explain underlying laws and theories using high level reasoning skills (Nivalainen, Asikainen, & Hirvonen, 2003). In other words, students are involved in the process of constructing qualitative models that help them understand the relationships and differences among the concepts. A number of studies have found that students who lack reasoning skills do more poorly on measures of conceptual understanding than their more skilled peers (Cavallo, 1996; Lawson et al., 2000; Shayer & Adey, 1993). For example, the concrete operational students or empirical-inductive (EI) reasoners, whose thinking are largely limited to direct observation were found unable to understand the formal concepts (Lawson, 1975). The difficulties that students have with formal concepts relate to their inability to apply scientific reasoning skills that are necessary for explaining the concepts. Gas Law, for example, is a topic that was found to be difficult for both high school and college students to understand because it requires the understanding of the behaviors of particles at the microscopic level (Nurrenbern & Pickering, 1987; Nakhleh, 1993; Chiu, 2001) and involves the use of direct and inverse ratios which require proportional reasoning, the ability to identify and control variables, and probabilistic thinking. These reasoning skills are essential for understanding the concepts involved because gas laws can only be defined in terms of other concepts (temperature, pressure, and volume), abstract properties, and mathematical relationships. Recent study, however, found that Malaysian students in Form Two performed very poorly in science items that relate to physics which involve scientific reasoning skills (Kementerian Pelajaran Malaysia, 2000; Martin et. al., 2000). For example, on a question for the top 10% benchmark that requires an ability to interpret data given in a table, compute the appropriate ratio, and explain their results, Malaysian students performed lower than their peers in 29 nations, and score much lower than international average of 38 nations (Martin et. al., 2000). Thus, methods of instruction in physics must emphasize the development of scientific reasoning skills as these skills are required for conceptual understanding.

Research studies have indicated that visualization of phenomena through computer simulations can contribute to student's understanding of physics concepts at the molecular level by attaching mental images to these concepts (Cadmus, 1990). According to Escalada & Zollman (1997), computer simulations provide opportunities for students not only to develop their understanding and reinforcement of physics concepts, but also to develop their skills in scientific investigation and inquiry. Inquiry-based science experiences conducted in relevant, meaningful contexts have been shown to develop higher order thinking skills in students (Roth & Roychoudhury, 1993). This is further supported by Cakir and Tirez's (2006) study that found inquiry-based science teaching and learning, with the support of computer simulation and collaborative contexts help learners to develop critical thinking and inquiry skills. Lawson (1995) cites literature indicating that the Learning Cycle approach that consists of Exploration, Concept Introduction, and Concept Application phases is an inquiry-based teaching model which has proven effective at helping students construct concepts as well as develop more effective reasoning patterns. Several studies involving adolescents in learning cycle science courses claim that the use of this instructional method in science classroom increased student understanding of science concepts and improved student reasoning abilities (Purser & Renner, 1983; Saunders & Shepardson, 1987; Schneider & Renner, 1980).

According to Vygotsky, a less skillful individual is better able to develop a more complex level of understanding and skill than he/she could independently through collaboration, direction, or help of an expert or a more capable peer. Scaffolding has been found to be an excellent method of developing students' higher level thinking skills (Rosenshine & Meister, 1992). Vygotsky's theories of scaffolding knowledge through peer discussion and interaction has been applied systematically under the rubric of "cooperative learning". Cooperative learning is an instructional technique in which students work together in structured small groups in order to accomplish shared goals (Johnson & Johnson, 1989). Research studies have clearly indicated the effectiveness of cooperative learning methods over either competitive or individual learning methods in the development of higher-order thinking skills as well as the achievement of greater learning outcomes (Johnson & Johnson, 1986). This suggests that with the help of sufficient scaffolding, or dynamic group support in cooperative environments, provided by inquiry-based computer simulations, an instructor, a more skilled partner, or a more capable peer, will enable concrete operational students to enhance their reasoning skills toward formal thought.

The meta-analysis study done by Lou et al. (1996) indicates that low-ability students gain most from being placed in heterogeneous ability groups because they receive individual guidance and assistance from their more able peers. Hooper and Hannafin's (1988) study also give evidence that low ability students improved their performance more than 50% when grouped heterogeneously. However, the low ability students have a higher risk of being excluded from group activities because they are seen by high ability students as being less competent (Whicker, Bol, & Nunnery, 1997). Alternately, low ability students may be motivated to learn by the effects of social cohesion inherent in friendship groups (Lou el at., 1996). Advocates of social cohesion perspective (Johnson & Johnson, 1994; Cohen, 1986; Sharan & Sharan, 1976) argue that the extent to which cooperative learning has an effect on student achievement will be mediated strongly by the cohesiveness of the group. This study, therefore, tested the 'diversity of intellectual abilities' hypothesis against 'group cohesiveness' hypothesis by placing students in heterogeneous ability grouping and friendship grouping, to investigate how much, if any, these groupings facilitated student's scientific thinking and conceptual understanding of gas laws within inquiry-based computer simulation and cooperative learning environment. In addition, the study explored the extent to which heterogeneous ability and friendship grouping affected learning for EI and HD students compared to their counterparts in traditional group work groups. Thus, three instructional methods were employed in this study: inquiry-based computer simulation with heterogeneous-ability cooperative learning (HACL), inquiry-based computer simulation with friendship cooperative learning (FCL) and inquiry-based computer simulation with traditional group work (TG).

PURPOSE OF THE STUDY

The purpose of this study was threefold. Firstly, it

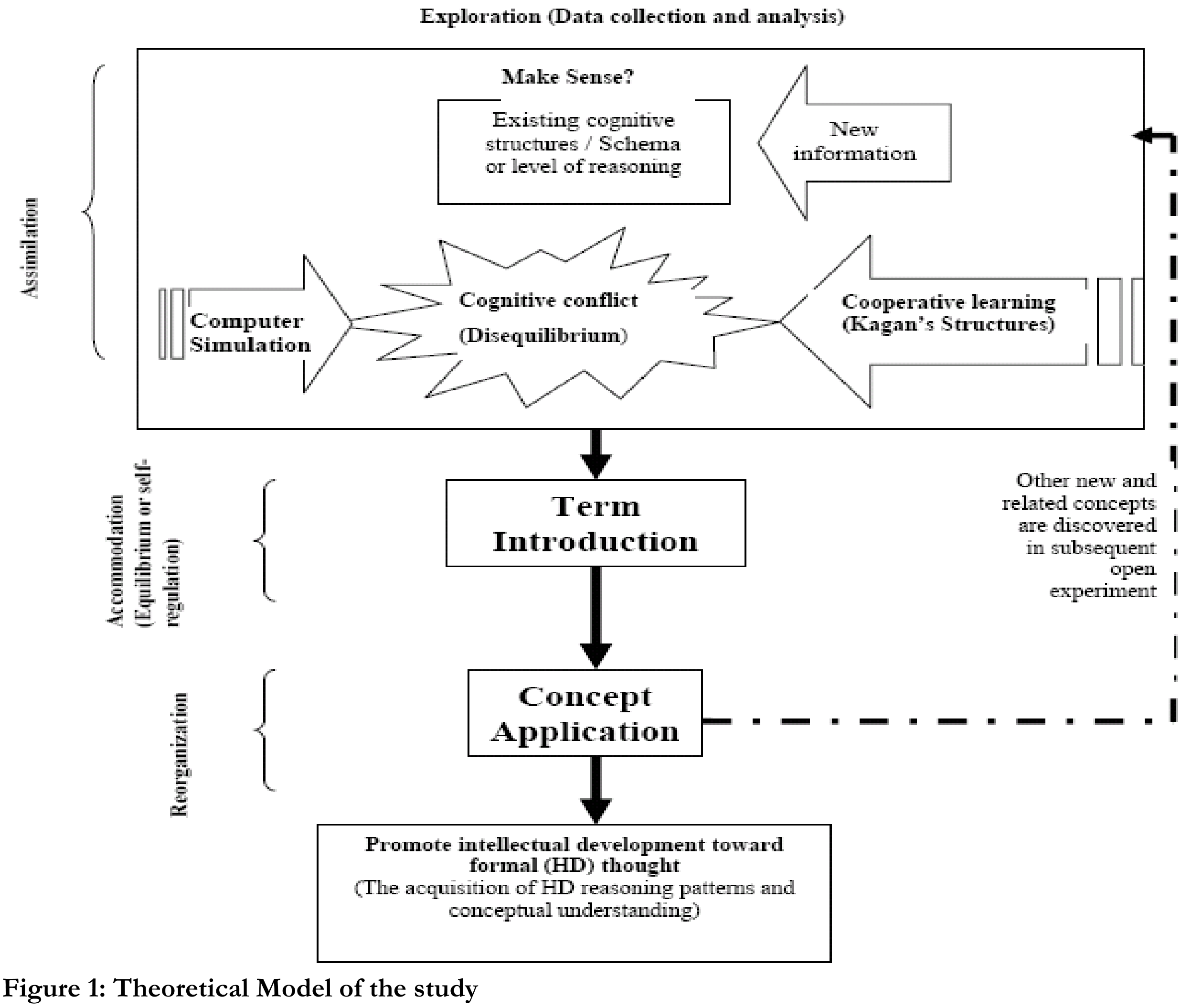

Figure 1: Theoretical Model of the study

was to investigate if there were any significant differences in student's scientific reasoning (SR) and conceptual understanding (CU) between learners who were taught in three different instructional methods. Secondly, it was to investigate the effects of these instructional methods on EI students and HD students in SR and CU. Thirdly, it was to investigate the interactions between the instructional methods and student's reasoning level on performance in SR and CU.

THEORETICAL FRAMEWORK

The theoretical framework of this study is based on Piagetian cognitive theory and Vygotsky's theory. Piaget (1952) believed that the cognitive development of students toward formal thought could be facilitated through three cognitive processes: assimilation, accommodation and reorganization. Vygotsky (1978), on the other hand believed that students are capable of performing at higher intellectual levels when asked to work in collaborative situations than when asked to work individually. He hypothesized that the social interaction extended the student's zone of proximal development, the difference between a student's understanding and potential to understand more difficult concepts. Based on these two theories, a theoretical model of the study was presented in Figure 1.

For this model, students might be exposed to inconsistencies and conflicts in their attempt to understand new information. Specifically, when the new information raises questions or complexities that an individual could not resolve with their accustomed patterns of reasoning. The desire to resolve incongruities between prior understanding and new information is accompanied by a feeling of imbalance or disequilibrium or cognitive conflict. As a result, students are required to resolve their cognitive conflict through visualization of physical phenomena via dynamic computer simulation and peer support in cooperative learning group. This will make them to recognize in what ways their current thinking fall short and reorganize their personal beliefs, as well as to go beyond their current thinking capability.

Students' active participation in collecting and analyzing data via computer simulation in cooperative learning group is designated as Exploration phase. This involves the interpretation of events in terms of existing cognitive structure or referred as assimilation. The Term Introduction phase promotes a new state of understanding or equilibrium or self-regulation when new concepts and principles are derived from the exploration experiences. Through the process of self-regulation, existing knowledge, or schema will be altered to allow accommodation to occur. The Concept Application phase provides additional experience that may aid students to discover further application of newly developed concept and principles, providing opportunities for re-organization to occur. Other new and related principles are discovered by the students through extension activity in the subsequent open-inquiry experiment. This provides additional time and experiences to further encourage self-regulation and for stabilization of new principles. Via this process knowledge is constructed by individuals and accordingly, peers interaction may present different perspectives that may lead students to reconceptualise their own thinking.

Through the three phases of Lawson's (1995) learning cycle, students' thinking is expected to progress from concrete thinking about physics concepts to being able to deal with those concepts on a formal, abstract level. Consequently, the present study was set up to investigate the extent to which the integration of the Learning Cycle approach to computer-based simulations and cooperative learning would result in improved performance of concrete operational students in scientific reasoning and conceptual understanding of gas laws.

HYPOTHESES

On the basis of theory and evidence of related research and theoretical framework of the study, the following hypotheses were postulated and computed at the 0.05 level of significance.

Hypothesis 1: Students taught via inquiry-based computer simulation with heterogeneous-ability cooperative learning (HACL) method will perform significantly higher than students taught via inquiry-based computer simulation with friendship cooperative learning (FCL) method who in turn will perform significantly higher than students taught via inquiry-based computer simulation with traditional group work (TG) method in (a) scientific reasoning, and (b) conceptual understanding of gas laws.

Hypothesis 2: The HD students taught via HACL method will perform significantly higher than HD students taught via FCL method who in turn will perform significantly higher than HD students taught via TG method in (a) scientific reasoning, and (b) conceptual understanding of gas laws.

Hypothesis 3: The EI students taught via HACL approach will perform significantly higher than EI students taught via FCL method who in turn will perform significantly higher than EI students taught via TG method in (a) scientific reasoning, and (b) conceptual understanding of gas laws.

Hypothesis4: There are significant interactions between the instructional methods and student's reasoning ability level in performance in (a) scientific reasoning, and (b) conceptual understanding of gas laws.

RESEARCH METHODOLOGY

Research Design

The study employed a quasi-experimental pre-test-post test / control group design. The 3x2 factorial design was employed to examine the effect of three different instructional methods on EI student and HD student's performance in scientific thinking and conceptual understanding. The independent variable was the three instructional methods: HACL method and FCL method (experimental group), and TG method (control group). The dependent variables were the learner's scientific reasoning ability and conceptual understanding. The second dependent variable, i.e., conceptual understanding was the degree to which a student's understanding of the concept at the particulate level of Gas laws corresponds to the scientifically accepted explanation of the concept. The moderator variable was the learners' scientific reasoning ability which was designated EI and HD levels.

Research instruments

The effects of the experimental treatments were assessed using four instruments. All the instruments used in this study were translated from English version into Malay language using "Back Translation Method" so that the respondents do not have problems in understanding due to language.

The Lawson's revised Classroom Test of Scientific Reasoning Skills, CTSR (Lawson, 2000) and Roadrangka's Group Assessment of Logical Thinking, GALT (Roadrangka, Yeany, & Padila, 1983) were used to measure the learners' level of reasoning ability. Each instrument consisted of 12 items measuring conservation of weight, volume displacement, proportional thinking, identification and control of variables, probabilistic thinking, combinatorial thinking, and correlational thinking posed in multiple choice formats.

The Gas Laws Performance Test (GLPT) was developed to assess learners' conceptual understanding. The test consisted of 10 items requiring students to give a brief answer to the question, and a reason for why that answer was given, while others required students to provide explanation to the phenomenon presented in the questions.

The Cooperative Learning Survey Questionnaire (CLSQ) was constructed to survey the perceptions of participants toward their performance measures on four elements of Kagan's cooperative learning structures. It consisted of 16 items grouped into four categories: Positive interdependence, Individual Accountability, Equal Participation, and Simultaneous Interaction. Each item was constructed on a 5-point, Likert-type scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

All instruments were tested for reliability in a pilot study by determining the Cronbach coefficient alpha. The Cronbach alpha reliability coefficients of GALT (Pre-test) and CTSR (Post-test) were 0.6095 and of 0.6785 respectively. The Pearson's correlation coefficient among CTSR and GALT was 0.536. The GLPT test was administered as pre-test and post test to each HACL, FCL and TG group. The Cronbach alpha reliability coefficient of GLPT Test was 0.8445. The overall alpha reliability coefficient for the CLSQ was 0.8256 and the internal consistency estimate of each component in the questionnaire ranged from 0.4869 to 0.6814.

The EI and HD levels of learners' reasoning level was measured using GALT. Students with scores of 0 to 6 were considered to be concrete operational (EI students). Students who accumulated scores from 7 to 12 points were classified as formal operational (HD students). In order to account for possible pre-existing differences in overall ability between the treatment groups, the pre-test scores of GALT and GLPT were used as covariate measures.

Research Sample

The samples consisted of 301 Form Four pure science students (mean age 16.4 years old) from four different Smart Schools in Kedah and Penang. The study employed three classes or approximately 90 students from each of four randomly selected Smart Schools. They studied "Gas Laws", one of the topics in the syllabus of Form Four Physics. The participating students in each school were randomly assigned to one of the three conditions – HACL method, FCL method, or TG method as intact groups.

The HACL group was assigned by the teacher so that it comprised of two HD students and two EI students based on their individual test scores in GALT. The students in FCL group were assigned to four-member cooperative groups by having them choose randomly four members of their class with whom they most preferred or desired to work together. The FCL groups were found homogeneous in terms of reasoning ability as evidenced by the student's pre-test scores in scientific reasoning. To determine whether FCL groups whose members chose to work together were perceived as cohesive, all students completed a nine-item Group Cohesiveness Questionnaire (Hinkle, Taylor & Fox-Cardamone, 1989) at post test. Overall, the FCL groups were found fairly high cohesive (M= 4.3038, SD= 0.5707) on a five-point Likert scale. The traditional group work group (TG) served as a control group. The students in this group were given the choices to select their own group members and to determine their group size.

Instruction with instructional materials

In this study, all groups received identical instructional packages: Gas Laws Simulation package (Figure 2). The Gas Laws Simulation Package consisted of a) Gas laws simulation; b) Molecular Laboratory Experiments (MoLE) Gas Laws Worksheet; and c) Learning Guide on creating a graph using MS Excel Spreadsheet, all of which were presented in a CD provided. The adopted gas laws simulation, categorized as iterative simulation, was a dynamic computer-generated graphic representation of molecular processes produced with Java Applet by Gelder, Haines and Abraham (2002). The simulation was embedded into the Gas Laws Simulation Package which was accessed as an Authorware package running on the CD.

The student was given step by step instructions on how to use the gas laws simulation and asked to explore the different parts of the simulation. A set of controls on Control Bar Region provided the student with the ability to vary the input parameters for the simulation. Students had to decide which variables to vary and which to keep constant before running the simulation and to make necessary observations. Each group of students then performed a set of experiments using predescribed instructions provided on Gas Laws Worksheet. The students were expected to discover mathematical relationships of gas laws from the graph created using Microsoft Excel Spreadsheets.

The implementation of learning group

The four key elements of Kagan's cooperative learning, i.e. Positive Interdependence, Individual Accountability, Equal Participation and Simultaneous Interaction were embedded into the structure of Gas Laws activities for HACL and FCL groups. To promote positive interdependence in gas laws activity, the task was structured using Roundtable, Think-Pair-Square, and Read–Think–Discuss–Write, so that every student must contribute for the assigned task and team members were obliged to rely positively on one another to make the task successful. For structuring a task to include individual accountability, each student was made accountable to the group for her/his portion of a task, such as graphing group's data and presenting group's result to other groups. Additionally, students were structured to take personal responsibility to understand the group solution to a problem and how that solution was obtained. Consequently, Numbered Heads Together was adopted with which individual student was randomly called on to present their group's answer during subsequent class discussions.

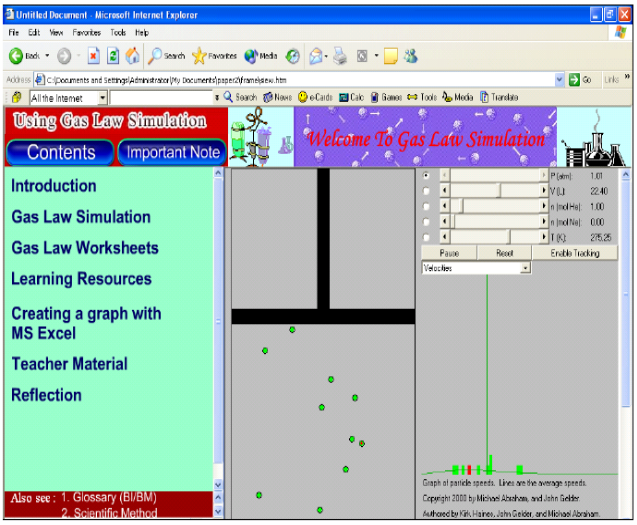

Figure 2. Part of the Gas Laws Simulation Package interface window

To ensure that the students participated equally, each student a) was assigned a different and important role in the group, such as reporter, recorder, checker, and team leader; and b) was expected to contribute to the discussion when his/her turn came by engaging in the tasks structured using Round Robin and Rally Robin. The tasks were also structured so that interaction occurred simultaneously both within and among teams. For example, using 'One stay, the rest stray' and 'Rally–Robin' structures for sharing information among teams and within pairs, active participation and feedback could occur for all students at a time. In order to ensure that each student committed to the assigned role, a learning contract was developed to be filled out by each group member.

The TG group experienced the same reactive effects of an inquiry-based computer simulation and group work as the HACL and FCL groups, but without the four key elements of Kagan's (1994) cooperative learning.

Administering the Study Sessions

The gas laws simulation activities sessions were administered in four separate sessions in different week, with 70-80 minutes for each session. The teachers of all instructional groups were provided a detailed lesson plan to conduct the learning activities. Prior to the start of first section, the teacher was requested to explain the specific requirement and procedure for the learning task. The first exploration phase of MoLE gas laws activity required approximately 40-60 minutes for students to complete. Prior to the investigations conducted in the study, the students had reviewed the concepts of gas pressure, and the basic principles of the Kinetic Molecular Theory of gases. A printed Gas Laws Worksheet was provided to guide the learners through the exploration phase which was primary intended to get the learners to experience the concept of Gas Laws to be developed and search for pattern of regularity from the graph created using Microsoft Excel Spreadsheets.

The students, in their group then carried on their second exploration phase and follow-up investigation in the following class lesson. The students in HACL, FCL and TG condition were expected to discover mathematical relationships of gas laws and explain phenomena in the gas laws simulation in their own group, with little help of the teacher. The teachers acted as a facilitator, monitored groups and intervened to provide task assistance if needed. Only after the students had thoroughly investigated, discussed, and attempted to logically explain the phenomenon, the teacher offered the students a more in-depth or scientifically accepted explanation and new terms. The students then engaged in a hands-on activity on 'Balloon in a bottle'. These experiences aided students in finding answers to questions that they had generated during demonstration prior to the beginning of gas laws activities. The teacher then posed a new situation or problem which can be solved on the basis of the previous exploration experiences and term introduction.

At the end of the teaching session four in each school, the entire class in all groups' condition was asked to complete the Gas Laws Performance test. The cooperative learning survey questionnaire and Classroom Test of Scientific Reasoning Skills were administered immediately after the students completed the Gas Laws Performance test. The students in the FCL groups were also asked to fill out a Group Cohesiveness Questionnaire.

RESEARCH FINDINGS

The data was compiled and analyzed using SPSS for Windows (version 11.5). Alpha was set at 0.05 level of significance.

The pre-Experimental Study Results

Initial screening tests indicated adequate conformity to all univariate and multivariate assumptions of MANOVA/MANCOVA for multivariate normal distribution in each group, homogeneity of DV variance/covariance matrices across groups in the population, the linear relationship between the covariates and the dependent variables, and linear relationship among dependent variables. A Chi-Square analysis revealed that the difference in group sizes were not statistically significant ($r = 4.76$, $p = 0.093$), thus the Pillai's trace was used to evaluate the multivariate differences. The groups were tested for equality and the results of MANOVA (Table 1) indicated that the HD and EI participants across the three groups were equivalent in scientific reasoning and conceptual understanding of gas laws.

The Experimental Study Results

Performed Post hoc pairwise comparison using the /lmatrix command (Table 2) showed that students in the HACL group significantly outperformed their counterparts in the FCL group ($p = .001$ and $p = .000$ respectively) who, in turn, significantly outperformed other students in the TG group ($p = .000$ and $p = .000$ respectively) in scientific thinking and conceptual understanding. Therefore Hypothesis 1 was supported. Also, HD students in the HACL group significantly outperformed their counterparts in the FCL and the TG groups in conceptual understanding ($p = .008$ and $p = .000$ respectively). Further, HD students in the HACL group significantly outperformed their counterparts in the TG group in scientific reasoning ($p = .004$), but did not significantly outperform their counterparts in the FCL group ($p = .107$). However, there were no significant differences between the performance of HD students in the FCL group and the TG group in scientific reasoning and conceptual understanding ($p = .224$ and $p = .219$ respectively). Therefore Hypothesis 2 was partially supported.

The results also showed that EI students in the HACL group significantly outperformed their counterparts in the FCL group ($p = .004$ and $p = .002$ respectively) and in the TG group ($p = .000$ and $p = .000$ respectively) in scientific reasoning and conceptual understanding. The EI students in the FCL group in turn significantly outperformed their counterparts in the TG group in scientific reasoning and conceptual understanding ($p = .018$ and $p = .005$ respectively). Therefore Hypothesis 3 was supported. An effect size in the eighties for comparing HACL and TG group indicates that the HACL method is an effective instructional method for promoting scientific reasoning and conceptual understanding. Overall, the HACL group outperformed FCL group with a relatively moderate difference on performance in scientific reasoning and conceptual understanding.

Finally, the results of MANCOVA showed that there was no significant interaction effect between instructional method and student reasoning ability level, as they related to scientific thinking and conceptual understanding of gas laws ($F(4, 586) = 0.74$, $p = .990$). This suggests that the effect of instructional groups did not depend significantly on the level of student's reasoning ability in both scientific thinking and conceptual understanding. Hence, hypothesis 4 was rejected.

Table 1. Summary of multivariate analysis of variance (MANOVA) results and follow-up analysis of variance (ANOVA) results on pre-SR and pre-CU.

Level	MANOVA Effect and Dependent Variables	Multivariate F	Univariate F
HD	Group Effect	Pillai's Trace 1.104 (p =.375), df = 4, 150	df = 2, 75
	Pre-Scientific Reasoning (pre-SR)		2.105 (p = .129)
	Pre-conceptual understanding of gas laws (Pre-CU)		.140 (p = .870)
EI	Group Effect	Pillai's Trace 1.772 (p =.133), df = 4, 440	df = 2, 220
	Pre-Scientific Reasoning (pre-SR)		1.210 (p = .300)
	Pre-conceptual understanding of gas laws (Pre-CU)		2.505 (p = .084)

Table 2. Summary of post hoc pairwise comparison

	Dependent Variable					
	Scientific Reasoning (SR)			**Conceptual Understanding of Gas Laws (CU)**		
Comparison Group	**Mean Difference**	**Sig**	**Effect size**	**Mean Difference**	**Sig**	**Effect size**
Between Instructional Groups						
HACL vs. FCL	6.099	.001	0.399	7.011	.000	0.514
HACL vs. TG	10.961	.000	0.766	12.436	.000	0.965
FCL vs. TG	4.861	.009	0.361	5.425	.002	0.417
Between HD students across the three groups						
HACL vs. FCL	6.479	.107	0.464	8.458	.008	0.662
HACL vs. TG	11.745	.004	0.808	12.730	.000	1.040
FCL vs. TG	5.266	.224	0.398	4.271	.219	0.393
Between EI students across the three groups						
HACL vs. FCL	6.120	.004	0.424	6.510	.002	0.643
HACL vs. TG	10.961	.000	0.853	12.247	.000	0.939
FCL vs. TG	4.841	.018	0.387	5.737	.005	0.446

Note. *The mean difference shown in this table is the subtraction of the second condition (on the lower line) from the first condition (on the upper line); for example, 6.120 (Mean Difference for SR) = HACL –FCL.*

DISCUSSION

The results of this study found that students who worked in HACL method outperformed those who worked in FCL and TG methods in conceptual understanding of Gas Laws. The results are consistent with cognitive elaboration theory which holds that explaining the material to someone else is the most effective means of learning (Slavin, 1987). The HD students in HACL group who held accountable to provide explanation to group members could examine their comprehension in detail, and this has been shown to lead to an awareness of inadequacies in their existing schemas (Collins & Stevens, 1982). When students gave the explanations, they needed to digest, connect, and combine the understood and newly developed concept they learned. According to Piaget (1952), this interaction with group members enable HD students to discover further application of newly developed concept, thus providing opportunities for cognitive restructuring to occur. On the other hand, EI students benefited from the immediate feedback and individual guidance that HD students provided, consequently helped them to clarify their own mental models and foster better understanding of gas laws. For example, the gas laws simulation engaged EI students to ask help from their HD group members to decide the best way of representing and interpreting the quantitative data.

Thus, the opportunity of EI students to work cooperatively with HD students in HACL groups increased their ability to think in HD form. In contrast, the students with homogeneous ability grouping in the FCL group might suffer from a lack of appropriately role models to provide explanation, thus they did not create as good a stage as students in HACL group for elaborate thinking, or for explaining processes to take place. As a result, students in FCL groups did not develop a better conceptual understanding of gas laws than students who taught via the HACL groups.

The results also showed that students who worked in HACL groups made significantly greater gains on the scientific reasoning test than those who worked in FCL and TG groups. The effectiveness of HACL method in promoting the scientific reasoning of students is consistent with cognition theories of Piaget and Vygotsky that social interaction is a force in mental development (Inhelder, et al., 1979; Vygotsky, 1978). In the present study, the HD students taught via HACL method acting as experts, developed or proposed methods and strategies that were successful in solving the given problems. The EI student was then given the opportunity to model these successful methods and strategies, while the HD students offering hints, scaffolding, and providing feedback to further develop the EI student's ability in hypothetical-deductive reasoning. Through the process of demonstrating appropriate strategies of approaching a problem, these HD students became more aware of the thinking processes they were using. At the same time, the EI students were given opportunities to compare - contrast their knowledge, reasoning in a specific domain with those of their HD peers. In this study, the Gas Laws Simulation provided interactive experience with physical phenomena that contradict students' prior conceptions. For example, some of the students had the idea that the speed of the particles increase as the volume of the container decrease, thus increasing the temperature; simulations allowed them to observe that there was no change in the average kinetic energy when the volume changed, therefore the particles could not be moving faster and there was no change in temperature. When the results of an investigation contradicted with what students had expected or with their prior concepts, mental disequilibrium occurred. With exposure to evidence that they gathered from Gas Laws simulation and different perspectives presented by their HD peers, EI students were able to reconceptualise their own thinking. This form of peer-peer cooperative learning represents Piagetian theory that provided EI students with the opportunity to extend themselves to higher levels of reasoning. Consequently, HACL method helped students to reason scientifically better than those taught via the FCL and TG method.

On one hand, the HD students in HACL group generally achieved at the same levels as did their counterparts in FCL group in scientific reasoning. The similar performances of HD students indicated that students had undergone brain growth plateau at age 16 and 17 (mean age 16.42 years). This could be explained by the view that improvements in scientific reasoning are a product of both neurological maturation and experience (physical and social) (Kwon and Lawson, 2000). With regard to the development of adolescence and early adult thought, for example, Inhelder and Piaget (1958) stated: …this structure formation depends on three principal factors: maturation of nervous system, experience acquired in interaction with the physical environment, and the influence of the social milieu" (p.243). Therefore, the present study suggests that instructional methods in promoting scientific reasoning among HD students can be effective if it is timed to occur after the plateau period in brain maturation.

The HD students taught via FCL instructional method did not perform significantly higher than their peers taught via TG instructional method in conceptual understanding and scientific reasoning. The results of this study are consistent with the results reported by Mullen & Cooper (1994) who found that, on average, correlational studies revealed a negative relationship between social cohesiveness and performance. Webb (1982) indicated that high ability students in homogenous groups might suppose that every one understands and then they reduce the interaction. In this regard, there was the potential that HD students in FCL groups who were cohesive became too confident about the ability of their group members to perform well and did not fully discuss the issues of importance or seek participation of all members to help them make decisions. Evans & Dion (1991) are also of the view that cohesiveness and productivity are negatively related as long as group norms discourage high productivity. A norm is a way of thinking, feeling, or behaving that is perceived by group members as appropriate (Asch, 1952; Sherif, 1936). Consequently, the cohesiveness-performance relationship is primary due to fact that the HD students of a FCL group developed norms that limited group member's participation to share their ideas and opinion. As a result The HD students taught via FCL method did not perform significantly higher than their peers in TG group in conceptual understanding and scientific reasoning.

The positive effects of FCL method on EI student's performance in scientific reasoning and conceptual understanding can be related to social cohesion perspectives that posit that students help one another learn because they care about one another and want one another to succeed (Slavin, 1995). As each group members wanted to stay in the group, and worked well together socially, they were dependent on one another, and hence promoted positive social interdependence among group members. This positive social interdependence, in turn, according to social interdependence theory, lead to promotive interaction as EI students within FCL group encouraged and facilitated each member's learning and output (Johnson & Johnson, 1989). It follows that the group members engaged in active learning behaviors, and hence promoted each other's success. As EI members of FCL groups engaged in frequent and open discussion, they increased their ability to develop more complex level of understanding and reasoning and therefore they outperformed their counterparts who taught via the TG method in scientific reasoning and conceptual understanding.

The students taught via TG method had significantly lower mean scores than those in the HACL and FCL methods in scientific reasoning and conceptual understanding. In this study, students taught via TG group were assumed to know how to work together and to be interested in participating and learning. Responses on the cooperative learning questionnaire indicate that the students responded very negatively to the fact that they were given an equal opportunity to participate to the group's task and that they were individually accountable for his or her contribution to the group work. The students taught via TG group were given a task to complete without the provision of structures that promoted the active and equal participation of all members. According to Kagan (1994), when the group did not structure for equal participation, the group discussion session could involve participation exclusively by the high achieving or extroverted students. When low achieving or introverted students saw their efforts as dispensable for the group's success, they reduced their efforts (Kerr & Bruun, 1983; Sweeney, 1973). Emerging from this, the students taught via TG group were not responsible for the part of the task and did not become individually accountable to their partners for doing their share and therefore group work resulted in some students doing most or all the work while others engaged as free rider. In addition, the students taught via TG group were given a task with no structuring or roles, and consequently group work did not hold each individual accountable to the group for his/her contribution. When group work did not structure for individual accountability, the students did not engage in the behaviors that increase performance by helping each other and encouraging each other to put forth maximum effort (Slavin, 1995). It follows that the interaction behaviors, including giving and receiving help, discussing, and sharing were lacking in a TG group. Consequently students had limited opportunities to discuss and share their ideas, or resolve contradictions between their own and other students' perspectives. As a result, students taught via TG group did not benefit much from group interaction than students did in HACL and FCL group.

The results of the study showed that the student's reasoning ability level did not significantly affect the performance of the instructional method. i.e., the EI and HD students benefited equally in SR and CU after learning in HACL or FCL or TG methods. Lawson & Bealer (1984) argued that successful qualitative reasoning arises as a consequence of the process of equilibration or self-regulation, that is an internal cognitive process whereby an individual's mental structures and some confusing external experiences interact over a period of time to eventually allow for the modification of previously incomplete and inadequate mental structures and the satisfactory "internalization" of the experiences (p. 421). In this regard, the acquisition of concepts and reasoning skills which was initiated by specific short-term instruction, as introduced in this study, did not become internalized. In other words, for EI students to progress dramatically from what Vygotsky called their "actual developmental level" to their "level of potential development", would require more long–term developmental processes. From the intellectual development viewpoint, the HD students have become increasingly capable of using a wide range of reasoning patterns (Lawson, 1995). Thus, despite working cooperatively and involved in self-regulation, they did not benefit as much from the instructional methods in scientific reasoning and conceptual understanding.

CONCLUSIONS AND IMPLICATIONS

In conclusion, the present study has found support for the hypotheses that the inquiry-based computer simulation with heterogeneous-ability cooperative learning method (HACL) is an effective mean of promoting students' scientific reasoning ability and conceptual understanding of gas laws in science classroom. The teachers should therefore manipulate the group's membership heterogeneously, as well as constantly monitor that the four elements of Kagan cooperative learning are being adhered to by each group for maximum effectiveness. The FCL method had a positive effect on EI students but not HD students. The EI students adopted norms for more positive behavior by engaging them in Kagan's cooperative learning structures than HD students did. The cohesiveness provided by EI membership in the FCL group promoted positive social interaction and promotive interaction that increased their ability to develop more complex level of understanding and reasoning than their peers in the TG group. Less effort in encouraging others from participating and not fully considering or responding to others' contributions in group task, all apparently interfered with the processes necessary for HD students to perform effectively in FCL group. The results of this study also indicated that learning groups need a clear cooperative goal structure if teachers wish to maximize performance on learning tasks when placing students in groups.

The findings of this study suggest that the HACL method is effective in enhancing scientific reasoning and conceptual understanding of gas laws for students of both EI and HD reasoning level. Therefore, the teachers need to become adept at recognizing the cognitive levels of their students, as well as how they interact with each other. Cooperative groups that composed of students of heterogeneous abilities need to be carefully formed after the teacher has built up knowledge of students' personalities, interests, skills and abilities before incorporating cooperative learning method into computer based instruction. In addition, teachers should provide EI students more opportunity and guide and assist them through HACL method. The EI students can perform almost as HD students as the findings of this study if they were lead appropriately. The teachers should engage students to think as scientists do as they analyze data and create theories and hypotheses. This could take the form of teaching thinking via web-based computer simulation which is available and easy to access. The instructional design should be refined in such a way as to push students to ask inquiry-based questions and create adequate alternative explanations for their findings that go beyond "our experiment didn't work".

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A Conversation between Dana Zeidler and Geeta Verma & Lisa Martin-Hansen: Exploring Further Possibilities in Science Education

Geeta Verma and Lisa Martin-Hansen
Georgia State University, Atlanta, GA, USA

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This interview conversation among Dana Zeidler, Geeta Verma, and Lisa Martin-Hansen took place at the NARST conference on March 30, 2008. The purpose of this dialogue was to reflect on Dr. Zeidler's career in science education and his research on science teacher learning. During the conversation, Dana Zeidler shared his career path, establishing his research in science education, pushing the conversation on socioscientific issues (SSI) as well advice for researchers and doctoral students in the field. The written piece includes a brief summary of Dana's career achievements, a list of our conversation topics, the transcript of the audiotaped conversation, as well as a list of Dr. Zeidler's selected publications.

Keywords: Career, science education, socioscientific issues

FOREWORD

Dana Zeidler is a professor of science education and the program coordinator for science education at the University of South Florida in Tampa, Florida. Dr. Zeidler received his Ph.D. in science education from Syracuse University, Syracuse, NY (1982); an M.S. in science education from Syracuse University, Syracuse, NY (1978); a B.S. in Education/Biology from State University of New York, College at Buffalo, NY (1976); and A.A.S. in Natural Sciences and Conservation, State University of New York, College at Alfred, N.Y.

Dr. Zeidler began his professional career in soil conservation. He made a shift in his career as he "preferred to work with people rather than test tubes, beakers, flasks and doing soil analyses." This led him to pursue teacher licensure in biology and general science at the high school level. He continued on to complete his master's degree in science education at the Syracuse University. He taught genetics, biology, evolution and science teaching methods as a graduate assistant during his enrollment in the master's degree program (and ultimately in the Ph.D. program). As he was immersed in the university climate, he began to understand that there is a broader field of science education and that interested him greatly. It was at this time that he decided to pursue his Ph.D. in science education. He began his

Figure 1. Professor Dana Zeidler

Correspondence to: Geeta Verma, Ph.D., Assistant Professor, Science Education, College of Education, MSIT, Georgia State University, PO Box 3978, Office #676, Atlanta, GA 30302-3978, USA
E-mail: *gverma@gsu.edu*

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teaching career as a middle school physical and chemical Science teacher at Altmar-Parish-Williamson Central School, NY. After receiving his Ph.D. from Syracuse University, he began his university career as an assistant professor at Delaware State University where he gained tenure and associate professor rank. Later (1989) he moved to the University of Massachusetts as an associate professor and senior faculty directly the science and mathematics education doctoral program. After seven years, he accepted a position at his current institution, University of South Florida (USF) where he obtained full professorship. At USF, he has been the program coordinator for science education (Doctoral, Masters and Undergraduate Science Education).

Dr. Zeidler has delivered keynote addresses to several professional organizations including the International Conference of Trends and Issues in Science Curriculum Materials Research and Development, National Taiwan Normal University, Kung-Kuan Campus, Taipei, Taiwan; Linnaeus Tercentenary 2007 Symposium, Uppsala University, Uppsala Sweden; National Taichung University, Taichung Taiwan and National Chaiyi University Conference on Socioscientific Issues, Chaiyi, Taiwan. He has been a recipient of many awards including the recipient for the 2008 Association for Science Teacher Education Outstanding Mentor Award; recipient for the 2006 *Journal of Research in Science Teaching* best article award (Troy D. Sadler & Dana L. Zeidler); recipient of the President's Faculty Excellence Award (USF, 2003); Award for recognition of service to AETS (as Managing Editor of the *Journal of Science Teacher Education*); and recipient of 2002 and 1999 Outstanding Position Paper Award at the Southeastern Association for Science Teacher Education. Dr. Zeidler is renowned for his work in the science education community specifically focused on socioscientific issues (SSI). He has presented 50 papers at international and national conferences, and published 33 refereed journal articles. He has authored one book, edited one book, and published 8 book chapters and two monographs (see Appendix).

Dr. Zeidler has been an active member of several professional organizations in science education such as National Association for Research and Science Teaching (NARST), National Science Teachers Association (NSTA), American Educational Research (AERA), Association for Science Teacher Education (ASTE), and Southeastern Association for the Science Teacher Education (SASTE). He has served in many leadership positions throughout his career in these professional organizations. He was elected to the Executive Board of Directors for the National Association for Research in Science Teaching (2006-2009), was elected to the Board of Directors for ASTE (2008-2011) and was elected the President (2000-2001) of the Southeastern Association for Teachers in Science (SAETS). Additionally, he was nominated to be the Conference Chair for the 2007 Annual Meeting of the Association for Science Teacher Education (ASTE), Clearwater Beach, Florida (2006) and to the Conference Coordination Committee (2006-2008) to the Association for Science Teacher Education (ASTE). In addition, he was elected and reelected as Managing Editor (1990-1994) for the *Journal of Science Teacher Education* (JSTE) published by the Association for the Education of Teachers in Science (AETS). He also has served on the editorial Board of Reviewers (1997-2002), for *Journal of Science Teacher Education* (JSTE) published by the Association for the Education of Teachers in Science (AETS), served on the Editorial Board of Reviewers for *Science Education* (1996-2005) and served multiple years on the Review Board for the *Journal of Research in Science Teaching.*

INTRODUCTION

Our professional association with Dr. Zeidler at regional conferences such as SASTE has allowed us to establish a collegial and informal association. As researchers and scholars in the southeastern part of the United States, we have had the opportunity to hear Dana Zeidler speak on a number of occasions. Our own research areas of inquiry in fields such as nature of science and equity issues intersect in a number of ways with Dr. Zeidler research interests in socioscientific issues (SSI). At these regional meetings, we have encouraged our doctoral students to seek out scholars in the field, including Dr. Zeidler, and have informal conversations to facilitate their lines of inquiry.

Recently, we came across the article in EURASIA *Journal of Mathematics, Science & Technology Education* that featured a conversation with Dr. Sandra Abell and her professional career. This made us reflect upon the benefit of such narratives especially for junior scholars and doctoral students in science education. Our Ph.D. students have shared their respect and admiration for the scholarly body of work and the ideas generated by Dr. Zeidler. Thus we felt it will be beneficial to the science education community to showcase the professional career of Dr. Dana Zeidler. In this professional narrative, we interviewed Dr. Zeidler at the 2008 International Conference of National Association of Research in Science Teaching (NARST) in Baltimore, Maryland. In preparation for our interview, we reviewed Dr. Zeidler's vita and found another interesting aspect. In addition to his work in the science education arena, Dr. Zeidler has also established two martial arts schools in

West Townsend Massachusetts and Land O' Lakes, Florida in conjunction with Pasco County Parks and Recreation. He is a Sensei (Chief) Instructor of the Zeidler's Isshinryu Karate Club. He noted in his vita that these schools are "not run as a business but for a love of the art stressing the fusion of mind, body, and spirit." He has studied Isshinryu Karate since 1982 and has been promoted to Roku Dan (6th Degree Black Belt, 2004) and has trained with Grand Master Angi Uezu in Japan.

Conversation Topics

We used the following conversation topics to guide the readers in our conversation with Dana:

- Dana Zeidler's journey leading him to his present position in science education
- Shaping of his professional career in science education
- Reflections on research perspectives linking nature of science and socioscientific issues
- Development of socioscientific issues as a line of inquiry in science education
- Advise for junior scholars and doctoral students in science education

In this section, we present a transcript of the audio-taped conversation and it is available on the journal's webpage. We use the following acronyms to represent the participants in this interview:

GV (Geeta Verma); DZ (Dana Zeidler); and LMH (Lisa Martin-Hansen)

GV: Tell us about your current position and what's your role and responsibility at your current institution?

DZ: Right now I am a professor at The University of South Florida. I am also the program coordinator for the science education and I have been there, now, for about 11 years, doesn't seem like that long but I am getting older and time is flying by.

GV: How did you begin your career in science education?

DZ: I began my career with a two-year degree in social and applied science and natural science's in agronomy and soil conservation. It's a two-year degree and [I] didn't quite know what I wanted to do after that except that I knew that I'd rather work with people rather than test tubes and beakers and flasks and doing soil analyses -- it was interesting to find [out] what it was but I didn't really want to think about doing that for the rest of my life. I went on for a Bachelor's degree at a State University of New York, Buffalo and I went to State Teachers College, Buffalo State College (at that time), and I continued my work in biological sciences, minor in physical sciences and earth science, and began taking educational courses and did my internship -- my student teaching, up there.

In New York State to be permanently certified, you need to get a masters degree within 5 years, so I thought that I would go right on to Syracuse University to accomplish that and something unplanned happened in Syracuse -- I was able to talk my way into an assistantship from day one of my Masters degree (and which is [something] they [had] never done before, usually its [only] PhD students only they hire for an assistantship) but, somehow, I got the right person at the right time and talked my way into a teaching assistantship in Syracuse University and taught courses in genetics and evolution, methods courses, as well as being a Master's student.

I had [a] large tiered lecture hall and [it was] pretty intimidating being a page ahead of the students at that time but it was a good training experience. At that point, I had an office similar to the doctoral candidates. I began to understand that there is a broader field of science education out there. At that time, I had only [an] inkling that there was only a field out there, to be honest with you. And once you are immersed in that kind of university environment with other PhD students, you begin to learn real fast that there is a whole network of relationships that go on in our own field. And [I] just stayed right on going to a PhD degree for science education.

LMH: Who were some of the people that you worked with during that time?

DZ: My main mentor was a man named Larry Schaffer, who had a physics background and was the most creative teacher I have seen in terms of teaching methods. Even though he has done this [methods] course for years and years, he [would] sit down before the class and rethink how to present something in bit of a different way, and in a more nuanced way, and he was very creative so it was a good training working with him.

I worked with Ann Howe, who is a former president of NARST and Marvin Druger to some extent, he wasn't on my committee but obviously I got to work with him and co-taught course with him -- a methods course. And at that time, probably my best friend and a fellow graduate student was Norm Lederman. He came in a few years after I started the program or maybe a year after I started or so, we went through graduate school together so I probably [have] known him longer than anybody else from NARST . . . and I still talk to him! [*GV*: that's a good sign.] He is an impressive figure and impressed me a lot... influenced a lot of my work, probably I'll talk about that later.

LMH: How about your dissertation? Where did you begin with your research?

DZ: Whenever I had an option to take an elective course even at the undergraduate level, I took a philosophy course or a psychology course, because I just had some affinity for it [as an] interest within me. And as I went on in graduate school, I began to see some underlying relationships between areas of developmental psychology and philosophy and things that I wanted to do with respect to getting kids engaged, reason, and learn to think. So I began taking a lot of courses in the Cultural Foundations Department which subsumed history, philosophy and sociology of education. And there is one gentlemen there who was the chair of the department by the name of Thomas F. Green, and now [is] the time to talk a little bit [about] him? ....I can do that … [*Interviewers:* Sure.]

I respect a lot of people but I wouldn't say I put people up on pedestals…people are just people. I made an exception in his case because he struck me as the exemplary case of an eminent scholar. And the seminars I had with him! I took every course...four or five different courses with him. Some of the courses [were] from [other] people in the Cultural Foundations department. The kind of the things that we were reading paralleled my interests with topics in moral education and moral philosophy.

I became interested in Kohlberg's work at that time as well too. Thomas F. Green ended up in my committee… but in order to really learn some of the presuppositions and the details of moral developmental theory, I convinced my chair person, who was pretty open about it, to send me to Harvard University for a part of the summer to take a long workshop with Larry Kohlberg, whose work is probably known for theories of moral development and [I] met some other post-doc students, [one] by the name of Marvin Berkowitz, one person who I'll [talk] about later. And their work obviously influenced me and got me really thinking about how people progress and reason and learn and make decisions based on social justice.

And I began to sort of apply that to science education, knowing that we have to do that kind of work with science education, as I said before, so I needed to find the bridge to science education and convince people [that] this [was] something of merit. At that time people would say "What does moral reasoning has to do with science education?" And my answer was "Fundamentally everything!" but I needed to convince people of that. So the foundation of my work began with looking at mediating factors of moral reasoning in science education

GV: And this was during your doctoral degree?

DZ: And that was in my doctoral degree.

GV: So did you doctoral dissertation specifically looked at some of [these ideas]?

DZ: That was the exact title.

GV: That was the exact title?

DZ: Right. I have a previous title but I changed it. I don't know if this all off the record or on the record. The first title was "Why Are There So Many A****s in the World?" [*Interviewers:*☺]. But that wasn't looked at [favorably] by the committee and so they asked me to modify that title to "Identifying Mediating Factors of Moral Reasoning in Science Education."

At that time, I looked at the capacity for people to reason both with formal reasoning ability and the differences between that and moral reasoning ability --- and there is a little gap or decalage between those two reasoning structures. And I tried to explain, in part, why that gap exists. And I would look at things like attitudes and comprehension of the area under consideration, people [making] judgments about that.

GV: So at that time I think STS was in full swing, right? [In the] 80's... around that time?

DZ: It was… coming up on the horizon because I began my Master's degree in 1976 and finished my doctoral degree by 1982, and STS was sort of coming on the horizon and would hit the same [time or] a little bit after that.

GV: Because one of your pieces talked about providing the theoretical framework for STS and that's how you transitioned your work from STS to SSI?

DZ: Right, if I can clarify. . . if I may [*Interviewers:* Sure.]. The STS movement didn't really provide any kind [of] framework for my work. In fact, at that time, I swear that it seemed to be lacking some crucial elements that I felt were important based on the work that I had been doing, and that framework would eventually, 20 years later [or] so, would [be] known as socioscientific issues or SSI, but if you want me to jump ahead to explain [a] little bit about the differences [*Interviewers:* go ahead].

I became interested in several aspects that I felt connected in some way to moral development and moral reasoning. I tried to find segues or portals in the science education [field] where it makes sense to look at that kind of work, and so I began doing some work in several areas. One included . . . some nature of science with Norm Lederman . . . another finger or branch was looking at argumentation and discourse and fallacious reasoning as well. Another work was that looking at developmental differences and moral judgment and cognitive abilities as well as . . . looking at also some sociological factors about the structures of society and how people think and reason in groups.

Eventually, I realized that the STS movement really didn't provide... in my opinion, a sound theoretical framework for its existence. To me, it seemed more like an ideology in search of a theory, than something [which] came from a theoretical base, and so I saw STS being a great advancement to begin thinking about connections among science and technology & society. Some individuals would begin to incorporate some elements of moral problems in that. But at best I saw, STS only alluding or kind of pointing out possible moral [kinds] of conflicts or problems or ethical considerations, but it didn't really compel people to seriously think and work in their way… to negotiate their way [through] these problems with respect to looking at character development, trying to see how people can progress through epistemological sophistication … different levels of epistemological reasoning.

I suppose that the lack of a strong theoretical framework or structure enabled me to begin combining those areas that I was looking at in a way that I thought was a better theoretical underpinning for developmental thinking and consistent with what people do in character education for social justice. That's why eventually I was able to,... many years later, kind of synthesize that work together and kind of incorporate that into the SSI or socioscience education framework.

LMH: Now it sounds like this connection began quite early in your career.

DZ: It did. I remember writing a piece that was a paper that didn't get into a published form but I presented it at an STS conference, the only one that I went to in Crystal City, Washington D.C., and the title of the paper had something to do with "STS and the Missing link in Science Education" and to me that missing link was the things that many years later came to unfold but I probably could not articulate it well and it wasn't probably a very popular position to take.

LMH: I was going to ask you how [was] the general reaction at that time . . . how did it go.

DZ: Polite, you know nods and [then] "Next ..." [*Interviewers:*☺] "We have another presenter at this point…" And I, quite frankly, I don't think my thoughts were well-developed at that point... looking back at them... I have that paper on my table and look at it and say "Naah . . . not going to convince anybody yet."

GV: What advice would you have for Doctoral students in terms of developing their own line of inquiry especially, let's say, they're trying to get into socioscientific issues and moral reasoning and these kinds of topics?

DZ: You need to have a passion for what you are going to do because it's your dissertation and I see so many students, not my students of course, but many other students [*Interviewers:*☺] that will take what's easy and doable and will also tend to be the kind of dissertations that are "so what?" and "ho hum and nobody really cares!" And to my way of thinking . . . and for my personality, if you are going to immerse yourself for such a long period of time then you ought to really have some real vested interest in this topic to be personally motivated to really push the envelope. And so I would say, if you are going to choose a topic [choose] something that's personally relevant to you-- but also you need to convince other people that it is relevant to the greater science education community. That's the thing that I had to tackle with and grapple with when I was doing my dissertation.

GV: Was that difficult?

DZ: Syracuse University was great at providing [and finding] us leeway to pursue our own interests whether they are coming from philosophy or sociology or psychology . . . as long as you can convince them and connect it [with] science education. As I just said, that nobody had really ever done the area that I worked with then. They were probably little skeptical at first but they gave me leeway to make the case. And evidently I successfully made that case for them. So that's my advice – to pursue the things that really interest you as long as they are of interest to some part of the science education community. And be willing to take these kinds of risks to explore topics that you think are . . . need attention because there are a lot of things that we still don't know about.

GV: So what advice would you have for junior researches trying to get published and are not as articulate . . . not well thought out because they are . . . early in the career but they are trying to do this kind of work which is not your traditional science education kind of scholarship?

DZ: Well like any sound research you need to do your homework. You need to see what's been out there. First, you need to engage in a reading program and look at the literature, look at the journals and look at other fields as outside of science education. [It has] to makes sense with respect to connecting to your interests too. And so [if] I limited myself to the science education literature, I could never advance this research program. I [looked] outside to the character education and moral philosophy areas as well.

And so my advice is to see what is out there and then see where the assumptions are that need to be explored a little bit further. See where the openings are for new ideas. [Where] I think SSI research is right now is probably where NOS research was 20 years ago. And this is my opinion – I think it's beginning to really open up. We are just in the beginning stages of opening up by virtue [of] looking at the [research] program. [At] NARST, for example, looking at the articles and the journals and seeing how people are beginning to take this idea and look at different aspects of it. So, it's a ripe area but you need to kind of see what the framework is first and go from there.

[My] final suggestion is, don't limit yourself to the American journals, and look at the international journals. I was guilty of that too; I was very ethnocentric in my thinking and didn't realize until later in my career (I mean on one level of course I did) but did realize these contributions that people from over the world have made [to] science education from the European countries; from Australia; from South America; from the Pacific Rim. Now that I have been traveling the world a bit more and beginning to look at those journals more recently, there are some really interesting works that can inform your work.

LMH: Now if we could travel back to time in Syracuse and then move on from there that was the beginning of your career in the academia. If you could continue on and tell us a little bit about where did you first began as an assistant professor and where was your research at that time and then just keep on going with us and lead us through your personal tour of where you have been with your research?

DZ: My first higher education position was at Delaware State University, Dover, Delaware. It was a small historically black college (HBC). I was attached to a program called the Learning Center and in that they took students who were "at risk" and [provide] them [with help in] their study skills and reading skills, and math and science skills. Of course, that's where I came in. And to develop a program that would try to position them better when they took their college level courses. [So] they wouldn't be blown out of their water and they can be more successful. And so retention was an important issue.

At that time, I really didn't think about having a research program proper. I just did what interested me and I don't know [if] that was wise or not. And maybe I was just a bit naïve to understand that "I need to have a research program." But I simply [did] the kind of research that interested me at that time and that's how I was looking at [it] . . . again some aspects of nature of science with Norm Lederman. And also looking at the differences between moral development and cognitive development. I didn't know exactly where [it] was leading but I thought there was [a lot of] work to be done and [it] interested me to do that kind of work.

So at Delaware I began teaching, I guess it's a kind of general science course or remedial science. I also began teaching for their masters program, only [an] occasional courses in science education, methods courses – sometimes a geology course too. And I also began at one point, [to] sort of work my way into taking over the research design and methodology course and the developmental psychology course, required by the masters students.

From there, (I was there for 7 years), I went up to University of Massachusetts at Lowell. It was an opportunity to work at the Ph.D. level because Delaware, at that time, only had master's degree programs. And I continued working . . . teaching strictly graduate courses and again, I taught the research design methodology course. I began teaching a qualitative inquiry course as well and then my specialty courses within science education and continued working.

At that point of time, I began looking at argumentation and discourse, and fallacious reasoning as well, and eventually moved on to the University of South Florida where I have been for a longer period of time, where a lot of my ideas got pulled together, as I described to you before, and began as an associate professor there and worked my way up to professor.

GV: How do your view changes in the field of science over the time that you've been involved in science education? What do you see in terms of big emphasis discoveries in the coming years?

DZ: That's a tough one because if I say the wrong thing, you are gonna come back at me and say "by the way you are wrong about this" [*Interviewers*☺]. I feel sort of safe in speaking in my own territories. As I mentioned before, I think socioscientific issues research because it branches out to epistemology, reflective judgment, moral reasoning, character development, and argumentation and discourse. I think SSI has the potential to be a really fruitful research program. And whether your SSI is the central core what you are doing, you could be working [on] any of those areas [and] will be able to connect to it. And the areas that I mentioned, I think, also [are] ripe for development . . . epistemological reasoning and reflective judgment.

NOS research, to me at this point, in a lot of respects for a lot of individuals in our field, [seems] to be mopping up kind of operations as Thomas Kuhn would describe – and has fewer people sort of taking risks to push it in really new directions. And again, I think, being able to create situations in the classrooms that where kids were practicing . . . real decision-making, going through evidence and seeing how people can support various positions based on [the] same evidence, has direct connections to nature of science research. So I think there is a kind of a new link that could be made with connecting nature science work with SSI and reflective judgment – that sort of thing. I hopefully have a paper coming out in JRST, if they like it well enough, that will tying a lot of those areas together – reflective judgment and nature of science within the context of socioscientific issues.

GV: In your own preparation, to do this kind of work, you said you took a lot of courses in cultural foundations and everything, so for us to prepare new Ph.D. student to go through this or work in this area then . . . that means we are kind of asking us to move them little bit outside of science education.

DZ: I think that's a good idea assuming that you have your strong philosophy department or cultural foundations or equivalent sort of department or psychology department, you know within a institution that sometimes might be limited at that persons institution, but to the extent that people can see that other disciplines that inform the work that you do and makes sense, I think that's a good thing.

After all, Ph.D. is a doctorate of philosophy and somehow we sort of leave off that later part out of our preparation . . . things that I was reading in a graduate school started with the fundamentals. Nichomachian Ethics – Aristotle, and Pluto's Republic and these were central to understand moral philosophy. I didn't fully understand it at that time but in hindsight I see it – working [my] way up through John Mills and other key philosophers. Eventually, I think those kind of your classic works provide a foundation where you can see links to present day ideas and provide a richer context for understanding the other theoretical work that you do. So . . . I am [often] moving people outside of certain boundaries and if sometimes [it] means taking a more than a minimum number of courses, what's wrong with that? Another semester or two in your total life – if it can really change your vision of the future.

GV: So what do you have your Ph.D. students do, the ones that you are the major advisor at your institution?

DZ: The same thing. There are certain courses in the science education that I am going to provide and offer. I have incorporated lot of things in my courses that I think they may not get in other places. And so some of the other courses that I teach for the Ph.D. level would be . . . things like moral education & science education, a moral reasoning and moral development [course] and a course in cognition and epistemology of science. I am teaching another course in nature and philosophy of science and kind of general trends course, to kind of see what the current issues are.

So, I probably [in]corporate a lot of things that are missing in other places in my courses-- but having said that, we have a lot of flexibility in our program for them to take course work in other areas too. So [if] somebody wants to really have a strong background in instructional technology, which is not my forte, they have the flexibility to do that as well and then hopefully they kind of bring their interest in science education into that area as well. So I try to encourage that.

LMH: You have been invited a keynote speaker, a number of times. Can you tell us a little bit about what people invite you to speak about at conferences?

DZ: Lately I have had the honor of going to different universities. More specifically, some universities in Taiwan like National University of Taiwan and Uppsala University in Sweden – they are interested to hear about the research program mostly in socioscientific issues is . . . and they left it up to me to present what aspects I think are interesting or relevant to people who are kind of newer to this idea.

And with respect, for example, to Uppsala University conference in Sweden, they wanted to see how socioscientific issues fit in with scientific literacy. And so I was I was trying to and (I have written on this topic before) . . .you know, make the case that scientific literacy wouldn't be fulfilled or reached without attention to some of these things. It certainly [has] the other aspects of the scientific literacy, but making informed judgments that have implications for the environment and social justice, and those kind of moral considerations, certainly need to be [a] part of what we would think of as being an informed scientific literate individual. So I was asked to speak about those kinds of things.

LMH: What kinds of questions did you have following those conferences? What were people curious about?

DZ: I would be making it up if I could recall specific questions . . . I can tell you that there seems to be lot of interest generated when I talk, whether it's the NARST conferences or the ASTE. The sessions were usually very well attended and afterwards, it's usually a number of newer faculty and sometimes older faculty and Ph.D. students that just want to know a little bit more about my thoughts on X, Y, Z – and they are becoming interested in doing research and some aspects on this – and I just have those kind of personal conversations with the people.

GV: What have been some of your greatest joys working in science education and struggles?

DZ: The best part of the job is working with other individuals which can also be a struggle [*Interviewers*:☺] as [you may] know too. I look at the students that I work with and they're all so bright and knowledgeable in areas I may not know about. And that always impresses me so I get better by my relationship with them. But working through the scholarship process, not just getting the dissertation – but the scholarship behind what it means to get a Ph.D., again that's meaningful in my mind, is the best part and when they begin to realize that I am [not] being obstinate or difficult for the sake of being obstinate or difficult that there is . . . you know . . . there's genuine issues at-hand that will elevate their positions in the long-run for what they want to do. I think in hindsight they kind of appreciate that, see the light and…

One of the best things that happened to me was a number of my graduate students, I have got about 20 + doctoral students of my own, they got together and wrote letters to ASTE, which is the Association for Science Teacher Education – to put me up for the Mentor of the Year Award and apparently they contacted other individuals from other institutions that were either new faculty or doctoral students that I helped one time or another. I don't know how they did this but they figured it out and so there was a really good array of letters that were written into the board on my behalf.

I didn't know this until they took me out at my birthday at a NARST conference in New Orleans last year, and we were eating together, about a dozen of us. I excused myself to leave the table for a few minutes. When I came back, no one was at the table! These students [were] playing a trick on me. On my plate was this folder and ribbons. Inside that folder contained all these wonderful letters that they had written – detailed letters – pages and pages . . . and then they came out from their hiding places and congratulated me! And so they put me up for that award – I told them that even if I didn't win that, the letters meant more than anything else. But in the long run, I did receive the Mentor of the Year Award. So that was really a satisfying experience and it was a nice feeling to know that students felt that kind of reciprocity toward me – [and] that I do really feel for them, as much as of a hard time I give them.

LMH: You mentioned earlier Dr. Green. In your career, were there any other teachers or researchers who have influenced you through the years?

DZ: Oh, there are so many brilliant people in our field alone too . . . and [if] I should pick one of them, yet leave out certain names [they] would be insulted – but I can certainly talk about individuals like Glenn Aikenhead who has written a lot on scientific literacy – but he is going to be [one] the first people that I think took a real empathetic view of what means to be a scientifically literate and begin to make some connections to ethical concerns in science as well. Looking at Norm Lederman's works with Fouad Abd-El-Khalick and the work that he has done with Valerie Akerson and Randy Bell at that time.

Some of the individuals kind of crossed over and made some connections to socioscientific issues as well. But their whole research program on NOS and they're doing connections to some things that I am doing – and [it has] certainly been an influential asset to me. I look at some of the other people's work like Dianna Kuhn and Jonathan Osborne and some of the colleagues that he works with in Europe on argumentation [and] discourse have certainly informed my work as well.

Outside of science education beside Thomas F. Green and Larry Kohlberg, there have been other individuals in moral education and [the] character education field that have influenced my work too. Most notably, I can mention Marvin Berkowitz, who holds the only endowed chair position in the country in character education. He is at the University of Missouri, St. Louis and I have invited him to be a keynote speaker at ASTE and talk to science educators about character as well. And he is so prolific in his own field and we've talked quite [a bit] -- some of his work has been influencing me of late. And there are many others . . . we can go on for a long time.

GV: Talking about your publications, which work or works would you consider, in your opinion, to be influential or influencing the science education?

DZ: Which did you like the best? [*Interviewers:*☺]

LMH: I like one of your books that you had come out a little bit ago here. You edited a book with Springer. "The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education".

DZ: Right. That was a piece that pulled a lot of things together. That was a book on the role of moral reasoning and socioscientific issues and discourse in science education. I wrote a number of chapters in there with other individuals as well and other people contributed to it that really had an interest in this area too. And that was a good opportunity to really pull together a lot of ideas. I am really happy with the book – seems to be pretty well received and I think that's also a good place for people to start if they want to know a little bit more about this area.

I have to say there are a lot of good papers that I have done with other individuals and I will be remiss if I didn't mention the name of Troy Sadler who is an Assistant Professor at the University of Florida. I think that Troy is also, while a new scholar, an exemplary scholar and his thinking has certainly influenced my thinking as well and hopefully some of me has rubbed off onto him too. The work that we have done together, I am very proud of – and I would say the one article that sort of got a lot of recognition in the field, I think, may be gotten me a few invitations to speak in other places – was the article where we did on our "Beyond STS" and then laying out the research agenda for socioscientific issues.

I knew that I was shaking some of the pillars, and you know, trying for the point of making a case . . . not tearing down one tradition but trying to show the real weaknesses of the STS tradition, and to show how that field could be moved in a different direction under the SSI framework. I tried to articulate in there, the rationale behind it and the reasons for it. Hopefully, I think we did a pretty good job and that seems to get a referenced quite a bit and got us a lot of recognition. So there [are] a lot of other papers that I am proud of but I won't tell you the specific ones . . . there are a lot of good ones. One of the papers is that I did with Troy Sadler, He was the first author of, in JRST was

"Patterns of Informal Reasoning in the Context of Socioscientific Decision Making" and that was voted for the outstanding article for JRST, 2005 – and of course, that was one that I am very proud of . . . to work with Troy on.

GV: So if we were to ask Dana to describe Dana, How would Dana describe himself? ☺

DZ: In terms of what part of my life?

GV: Your professional. If you want to throw in your personal, you are more than welcome.

DZ: That's a hard one. I have tried to break down the barriers that naturally exist between professors and students. I think it's an artificial divide but I know it's partly institutional; it's there too for a reason. But I have always tried to strip away that and begin a personal relationship with my students. That doesn't mean that we have to be best friends but the point is we are both individuals. Even though I am on the one side of the fence and they are on the other, I never really saw that there has to be a fence there. And I guess I have been as successful as I have been with my students because I see them as smart people that can help me out. And they are creative in their thinking and [their] ideas -- and they'll challenge me and push me in [new] directions. I think I am rather adept, now [at] challenging them and pushing them . . . it's a two way street in our seminars and in our courses and I think that they have the freedom [and] flexibility to ask anything of me and challenge on any front or level. But again it's a two way street and we both are better for it.

Concluding thoughts:

We as interviewers recognize that we have only touched upon on Dr. Zeidler's contributions to the field of science education. Hopefully, this article will enable members of the science education community to not only recognize his contributions and his interests outside of his scholarly work.

Appendix: Selected Publications, Dana Zeidler, 1984-2008

Abell, S. K., & Pizzini, E. L. (1992). The effect of a problem solving inservice program on the classroom behaviors and attitudes of middle school science teachers. *Journal of Research in Science Teaching, 29*(7), 649-667.

Zeidler, D.L., Sadler, T.D., Callahan, B.C., & Applebaum, S. (In Press). Advancing Reflective Judgment through Socioscientific Issues. *Journal of Research in Science Teaching.*

Zeidler, D.L. & Nichols, B.H. (In Press). Socioscientific issues: Theory and practice. *Journal of Elementary Science Teacher Education.*

Dolan, T.J., Nichols, B.H., & Zeidler, D.L. (In Press). Using socioscientific issues in primary classrooms. Journal of Elementary Science Teacher Education.

Zeidler, D.L. & Sadler, T.D. (2008). The role of moral reasoning in argumentation: Conscience, character and care. In S. Erduran & M. Pilar Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 201-216). The Netherlands: Springer Press.

Zeidler, D.L. & Sadler, T.D. (2008). Social and ethical issues in science education: A prelude to action. *Science & Education, 17*(8, 9), 799-803. (Guest Editors for Science & Education Special Issue on: Socio-ethical Issues in Science Education.)

Fowler, S.R., Zeidler, D.L., Sadler, T.D., (2008). Moral Sensitivity in the Context of Socioscientific Issues in High School Science Students. *International Journal of Science Education.* In Press.

Walker, K. A. & Zeidler, D.L. (2007). Promoting discourse about socioscientific issues through scaffolded inquiry. *International Journal of Science Education, 29*(11), 1387-1410.

Zeidler, D.L., Sadler, T.D., Simmons, M.L. & Howes, E.V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education, 89*(3), 357-377.

Sadler, T.D. & Zeidler, D.L. (2005). Patterns of informal reasoning in the context of socioscientific decision-making. *Journal of Research in Science Teaching, 42*(1), 112-138. (Awarded JRST Outstanding Article for 2005.)

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