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EDITORIAL

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We would like to thank to the editorial board of EJMSTE for their voluntary support. Please do not hesitate to send us your valuable comments and suggestions. The journal will publish refereed papers, book reviews and information about conferences, and provide a platform for exchanging views related to educational research.

We are very sad to learn the shocking death of Dr. Jim Kaput, the distinguished member of editorial board and wish our condolences to academic world for this enormous loss.

Dr.Hüseyin BAĞ
Editor in Chief

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E U R A S I A
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Welcome to the ***Eurasia Journal of Mathematics, Science and Technology Education***. We are happy to launch the first issue with the contribution of individuals from all around the world both as authors and reviewers. Both research and position papers, not excluding other forms of scholarly communication, are accepted for review. The long term mission of the EJMSTE is to continue to offer quality knowledge and research base to the education community and increased global availability of the articles published each issue. The editors and review board hope that you find the published articles academically and professionally valuable.

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TEACHING SCIENCE AND MATHEMATICS FOR CONCEPTUAL UNDERSTANDING? A RISING ISSUE

Harcharan Pardhan

Razia Fakir Mohammad

ABSTRACT. Working with in service science/mathematics teachers at the Aga Khan University Institute of Educational Development, Karachi, Pakistan we find that even though the teachers take aboard innovative ideas, they find it challenging to implement the newly acquired ideas primarily because of their inadequate subject matter knowledge. In this paper we will describe and discuss select case studies from Pakistan to provide evidence regarding this issue and support it with literature from other parts of the world. We will finally share some implications and possible alternatives to address this issue.

KEYWORDS. Conceptual understanding; Pedagogical content knowledge; Pedagogical knowledge; Rising issues; Subject matter (content) knowledge; Teaching science and mathematics.

INTRODUCTION

In recent years there have been signs of conceptual shift in the practice of teachers from traditional to innovative methods. Teacher educators at the Institute for Educational Development, Aga Khan University (AKU-IED), Karachi, Pakistan view a teacher as a facilitator in supporting and developing students' thinking capabilities in general and science and math in particular. This is to enable the students to become responsible and informed individuals within the society and also to assume responsibility for their own learning. Therefore, the notion of teacher's new role in the context of teacher education at AKU-IED has been interpreted from the constructivist philosophy that suggests characteristics for teaching in accordance to a child's psychological and social perspectives of learning in the classroom. The teacher educators thus view a teacher as a facilitator in supporting and developing students' thinking. In theory, then, a teacher is expected to set tasks for the students and analyse outcomes of the tasks in order to understand how students construct meanings, listen to the other students, understand their level of thinking, and help them to achieve a common agreement of a concept (Cobb, et al., 1991; Jaworski, 1994).

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The teachers' engagement and experiences in the teacher educational programmes at AKU-IED generally lead to a change in their teaching perspectives on what mathematics and science teaching could or should be and what could be the limitations of the traditional mode of teaching for students' learning of the school subjects e.g. mathematics, science, and social studies. Findings from our experiences of working with teachers indicate that even though innovative teaching has been considered by the teachers to be desirable, the teachers in most cases can not successfully implement innovative methods for reasons that stem primarily from their own content (subject matter) knowledge.

Our findings concur with studies from other parts of the world that teachers need a good, basic conceptual understanding of content, in addition to pedagogy in order to shift their practice towards the promotion of student thinking. The discussion in this paper will focus on mathematics / science teachers' knowledge base needs particularly subject matter in planning and implementing innovations for conceptual understanding in their classrooms. The data (anecdotes/examples) that will be used in this paper for discussion and arguments is from our doctoral study field work and reflections of our own practice of working with teachers.

THEORETICAL FRAMEWORK

Shulman (1986; 1987) and Borko and Putnam (1995) suggest that a good knowledge of the subject is needed by teachers when designing curricula, lesson plans, and related instructional strategies which address the learning needs of students. In this regard Shulman has introduced a knowledge-base of teachers that;

> *Identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction (1986 P. 8).*

This special knowledge of the teacher Shulman (1986) called pedagogical content knowledge (PCK). According to Shulman, (1986) pedagogical content knowledge includes an awareness of ways of conceptualising subject matter for teaching. The author has elaborated (PCK) as follows:

> *Understanding the central topics in each subject as it is generally taught to children of a particular grade level and being able to ask the following kinds of questions about each topic: what are the core concepts, skills and attitudes which this topic has the potential of conveying to students? What are the aspects of this topic that are most difficult to understand for students? What is the greatest intrinsic interest? What analogies, metaphors, examples, similes, demonstrations, simulations, manipulations, or the like, are most effective in communicating the appropriate*

> *understandings or attitudes of this topic to students of particular backgrounds and prerequisites? What students' preconceptions are likely to get in the way of learning? (1986 P. 9)*

This means that teachers need to ask questions to increase their own special form of professional understanding of teaching, for example, what are the aspects of this topic that are most difficult for students to understand? What students' preconceptions are likely to get in the way of learning? Swafford (1995) further goes on to suggest that teachers do not need to know only general aspects of classroom teaching and techniques of teaching but also need to know methods that are specific to the subjects. Thus, it is important that pedagogical knowledge of mathematics / science develops alongside knowledge of mathematical / science representations and of students' thinking. Pedagogical knowledge, thus, must include knowledge of mathematical / science representations. This in turn means for teachers to have a deeper perspective of the subject both from content as well as pedagogy point of view.

Since the introduction of the concept of pedagogical content knowledge by Shulman in 1986 other components like students' misconceptions Grossman, (1989), and learning environment (Cochran and Jones, 1998) have been added for students' meaningful learning. Ball (1990) emphasized that teachers themselves also need a deeper understanding of mathematical processes in order to understand students' thinking. Magnusson, Krajcik and Borko (1999) further presented nine orientations as part of pedagogical content knowledge for teaching of science (could be equally applicable to mathematics) process, academic rigor, didactics, conceptual change, activity-driven, discovery, inquiry, project-based science, and guided inquiry. In light of the nine orientations pedagogical content knowledge can be considered as, "an important construct for describing the role of teachers' knowledge in facilitating the students' knowledge development, particularly for complex subject matter such as mathematics/science" (Magnusson, Krajcik and Borko, 1999 : 4-5). Pedagogical content knowledge, then, is the knowledge base of a teacher that enables him/her to transform the subject matter knowledge and curricular activities into classroom.

Undoubtedly, to transform the personal subject matter knowledge into meaningful, purposeful way to promote students thinking means that teachers first and foremost need a good, basic conceptual understanding of the subject matter knowledge. A number of research findings also reveal this. Research - based theories outlined by Grossman (1992) of teachers learning to teach also favour teachers' growth in their understanding of subject matter as a starting point with the belief that "thinking about the teaching of a subject matter can influence what teachers will later learn from classroom practice" (p. 176). Fennema and Franke's (1992) Cognitively Guided Instruction (CGI) project in the area of mathematics education considered the question of whether teachers can better facilitate student learning when they are knowledgeable about how students learn mathematics. They endorsed the idea that children's ideas / thinking, when appropriately integrated in sound manner and made part of the curriculum, can influence the teaching and learning of mathematics. This model implies that the teacher's conceptual understanding and cognition of the subject matter knowledge is crucial to student learning. This can be said of science teaching as well. Smith and Neale (1989), conducted a summer program for 10 primary science teachers to understand, facilitate, and document conceptual change in teachers content knowledge and the teaching and learning primary science. They reported that as the participating teachers changed their understanding of the subject content and how to teach it using effective strategies, they also taught differently. From Shulman's (1987) perspective of 'pedagogical content knowledge' teachers' ability to teach was enhanced. The authors further go on to write:

> *Teachers' knowledge of the content (emphasis is ours), their translation of that content into appropriate and flexible usage in lessons, their knowledge of children's likely preconceptions to be encountered in lessons and the effective teaching strategies for addressing them, and especially their beliefs about the nature of science teaching, all proved to be critical components in the changes they were able to make in their teaching. (Smith and Neale, 1989, p. 17)*

The authors' work informs us that teachers' own content (subject matter) knowledge understanding is one of the critical components of teachers' knowledge base to teach effectively through innovative approaches. Nilssen (1995) and Borko et al. (1992) have cited examples from knowledge domain of mathematics about student teachers that after several attempts in trying to rectify a situation while implementing innovative ideas lost control and reverted to convential methods. This was also observed by Pardhan (2002) who worked with a group of in-service teachers at AKU-IED, Karachi, Pakistan. Furthermore, even some of the course participants of the institute who had become reflective practitioners shared their experiences to this effect. An anecdotal evidence being:

At times during a lesson when confronted with a question I would get stuck and would not know how to answer the question or give a satisfactory explanation. Once, while students were discussing the particle being the smallest 'unit' of matter, one student argued"… but I have read that particle (atom) consists of electrons, protons and neutrons. So how can a particle itself be the smallest part of the matter?" At that moment I felt myself blank and did not know how to respond to the student. I knew a lot about the individual concepts but I could not link them to help my students to understand what 'unit' meant. As a student I learnt science mainly through traditional approach: this is why I think I am facing problems. My lack of content knowledge is also affecting my pedagogical skills. (Journal entry of student teacher, 1999. Emphasis ours. Used with permission.)

Fennema and Franke (1992) had also revealed that mathematics teachers need a good basic conceptual understanding of the subject matter (mathematics) and the pedagogical knowledge (mathematics knowledge) to shift their practice from "telling" to promoting student thinking. As the anecdote above suggests the authors' findings hold true even for science teachers. A number of other research findings also support the argument that content (subject matter) knowledge of the teachers is a critical component of teachers' special knowledge (PCK) from teaching perspective. The examples of studies that follow are from mathematics field, however, these can be applicable to the science field as well. The anecdote above from a science lesson support this.

Research findings of Lampert, (1988), Clarke, (1995) and Spence, (1996) revealed an unfamiliarity of new teachers in the secondary schools with the content of mathematics and the processes of concept building that affected students' mathematics education. The authors thus suggest that an important development should include improvement in the quality of these teachers' knowledge of school-level mathematics. Clarke (1995) reported that the teachers had personally, as students, studied a mathematical topic in isolation from other topics, which was not enough for them to promote conceptual understanding amongst students. Lampert (1988) questioned limited mathematical knowledge of a teacher in relation to achieving his or her new aim, of promoting students' mathematical thinking, in a classroom, "how can a teacher who lacks a 'network of big ideas' and the relationship among those ideas and between ideas, facts and procedures develop these things?" (p. 163 - 164)

Eisenhart et al (1993), in their description of a teacher's attempt to teach the division of fractions revealed a gap in the primary teachers' knowledge of the underlying structure of mathematics in terms of relationships and interconnections of ideas and their meaning to mathematical procedures. In their research, the teacher, himself, was unable to explain what it meant to divide, or to use different forms of representations, or to link the division of fractions with whole numbers. The teacher's incomplete knowledge-base hindered his decision to implement innovative teaching methods in the classroom. The authors research besides the teacher's lack of conceptual understanding of fractions, also identified a number of other factors (such as pressure of syllabus, workload) that inhibited him from teaching topics conceptually.

Ma, (1999) found that a limited knowledge of mathematics restricted a secondary school teacher's capacity to promote conceptual understanding among students. Ma's research revealed that the teachers, in her research, knew about new methods of teaching but their limited subject matter knowledge did not let them achieve their new aims of teaching for conceptual understanding. The author reasoned this to be because of teachers' own experiences of learning of mathematics without understanding conceptually. Ma illustrated this by describing problems with the mathematical knowledge of several experienced teachers, that lead to difficulties in teachers' trying out new ideas in their own teaching. The teachers as a result of their engagement in a teacher development programme had come to believe that there was a need for, both, to remember and also to understand procedures. However during their classroom practice while teaching topics like multidigit number multiplication their approach was still predominately based on memory of procedures rather than on understandings. Spence (1996) examined issues surrounding the mathematical knowledge of two teachers in their beginning attempts to teach mathematics. The author noted that the teachers' limited understanding of mathematics as a subject blocked their understanding of the students' learning processes and did not allow the teachers to analyse their own teaching practice. The author also found that one of the teachers was not even able to recognise her own lack of understanding of mathematics. Hutchinson (1996) reports that beginning teachers' problems with mathematical knowledge can frustrate them to a point that they find it safer to revert to traditional approach:

> *Even though Kate [the teacher] had a strong background in mathematics, she became frustrated when activities challenged that knowledge and appeared to revert to traditional method as the "one right way". Her previous learning in the domain did not appear to be conceptually developed to allow for new challenges to that knowledge. (p. 182).*

The above discussions, literature review and research findings suggest that the subject matter knowledge of science/mathematics teachers is crucial for shaping or reshaping their practice. This has also been our experience of working with mathematics and science teachers in Pakistan. In this paper we will share our similar experiences, learnings and their discussion and implications.

FINDINGS

The subject matter (science/mathematics) understanding of the teachers who graduate from the in service teacher development programme from AKU-IED, gets challenged as they teach mathematics or science with reasoning. Teachers' limited conceptual understanding of the content and heavy reliance on the prescribed textbook methods and particular answers becomes evident when they express their respective subject matter point of views while planning, teaching and analysing their lessons beyond the textbook. Teachers' limited understanding of the subject matter hinders their attempts to incorporate their new learnings in the planning of lessons making connections of their innovative/new ideas with the textbook methods and designing alternative assessment. Teachers perceive all this as a barrier to their own mathematical/science assumptions and their students' examination. In this paper we will use specific examples or anecdotes from our field based experiences of working with the participant teachers of our doctoral studies (Pardhan, 2002; Mohammad, 2002) to discuss further the above stated problems.

Teachers' Planning Processes

The examples from our wider set of experiences and their analysis revealed that problems with subject knowledge presented a barrier to the teachers in unpacking the conceptual underpinning of the subject specific procedures when they made effort to plan lessons according to their new vision of teaching. Most of the teachers at times were unable to review, clarify and rationalize the subject matter related assumptions behind the textbook exercises or while trying to teach beyond the textbook. For example in a pre-observation conference with a teacher educator, a teacher (Naeem) expressed his desire to plan a lesson on percentages for students' conceptual understanding. He shared that prior to AKU-IED experiences he had mostly used the textbook method with his students (he became silent and looked at the teacher educator). In order to pursue the talk the teacher educator asked Naeem to share his understanding of the topic. In response Naeem just restated the textbook given method 'multiplying a fraction by hundred converts it to percentage. He could not provide further explanation although the teacher educator tried to probe and prompt him. To initial Naeems' thinking beyond textbook the teacher educator suggested some real life examples on percentages e.g. exam grades, discounts, and tax and also discussed what they meant. This helped Naeem to recall the textbook definition of percentages as a part out of hundred. Discussion enabled Naeem to recollect his AKU-IED experiences, basically, what resources the programme facilitators used and he shared this with the teacher educator. He then thought of using some of those ideas e.g. making some posters of daily life commercials such as '20% extra toothpaste', '50% of the cost'. The rationale to use these posters he stated would be to initiate students discussion on percentages to enable them to explore the meaning themselves. However, in the middle of the discussion Naeem started raising concerns about accessibility of resources and arrangement for displaying the posters by saying "there is no material available in school and no arrangement of hanging charts in the classroom" [1](field notes January 6, 2000). In response to this the teacher educator tried to encourage Naeem to think of other alternatives which could work in his situation e.g. using chalkboard and oral discussion, Naeem's position in this regard is reflected in his words:

> *The writing could take more than 10 minutes, and in a 30 minute period, I do not think it is possible to teach a complete lesson. I do not think that verbal examples could motivate children to participate in the discussion. Children need stimulus; this is the beginning [to apply different methods] [2](6 Jan, 2000).*

As the dialogue above reveals, for Naeem to plan a lesson beyond the textbook for percentages proved to be a demanding task. The teacher educator felt, perhaps, an equivalent fraction approach would enable Naeem to come up with a plan. The teacher educator thus suggested to Naeem to review equivalent fractions and building on it to help students to develop the meaning of percentages; Naeem liked the idea and wanted to give it a try. However, it did not take him long to turn back to the teacher educator saying "how can I teach fractions and their relation to percentage, at the same time complete the textbook exercise in limited time in one

[1] Similar concerns have been raised by a number of science graduates as well. Some examples are "materials are not available…no space to store materials, models and charts…" (personal notes)

[2] Time is constraint…I had to achieve all the objectives…I could not… reading process for the students is problem…discussion in some things becomes long…and planning could not be completed on time… (Immediately after lesson self-reflection Saira September 27, 2000)

lesson (field notes Jan 6, 2000)[3]. Naeem found it difficult to plan a lesson beyond the textbook approach and explanations.

The example given above reveals the teacher's limited mathematical knowledge hindered him to explore alternate method of teaching. The teacher wanted to plan a lesson on percentages, but he was unable to discuss the meaning of percentages, their relation to fractions, the assumptions underlying the relevant formula, and the application of the formula in other new situations. Teachers' subject matter knowledge was solely restricted to the textbook and it was also found to influence their handling of students' responses or answers.

Handling students' responses

During the study it was found that limited subject matter knowledge was problematic for teachers to handle student responses or answers effectively. Teachers were unable to analyse content related assumptions behind students' responses or to use student answers to further enhance students' content understanding. The teachers struggled to attempt to reconcile a new method of teaching with their limited subject matter knowledge. This lead to the teachers recognizing their inadequate conceptual understanding. The effects of this on teachers' behaviours were; rephrasing the students verbal expressions; ignoring students' answers; and imposing own or textbook knowledge on students without understanding. The above conclusions are based on a number of lessons observed of the teachers. A selected sample anecdote is shared as evidence.

In a lesson on 'equations' a teacher [Sahib] ignored students responses in which either the student explanations were different from the one in the textbook or [Sahib] was unsure of the correctness of the response. Sahib had some of the students to come up to the chalkboard and solve equations. He encouraged them to provide reasons and explanations for their method. He started them off by using simple (e.g. $x + 7 = 9$) equations and then he moved the students to more difficult ones ($2x - 3 = 1$). This is when [Sahib] faced problems as the teacher [Sahib] - student talk in the box below reveals.

The teacher invited a student to the chalkboard to solve the equation $2x - 3 = 1$	
1 T	What will we 'cancel' first?
2 S1	Three
3 T	Good
4 T	What is the sign with three?
5 S1	Minus
6 T	What does minus three mean?
The student without speaking….. on the chalkboard writes $2x = 4$.	

[3] Syllabus is a problem…some discussions become long and we rush to complete the syllabus. (Immediately after lesson self-reflection Saira September 27, 2000)

7 T Think again

The student (S1) did not respond….moving away from S1 and addressing the other students the teacher asked,

8 T Who will tell the meaning of minus three?

9 T Good. Yes, who will tell hmm…?

10 T We add three to one side and do the same operation on the other side…(no response from students…they looked confused).

The teacher moved to the student (S1) again,

11 T What next?

The student (S1) wrote, x = 2

So far student (S1) has responded well to the teacher's mostly recall type questions; however teacher [Sahib] hardly acknowledges. It appears Sahib wants explanations along the lines of the textbook.

12 T Why is x equal to 2? Sahib is attempting to probe student's (S1) understanding

The student without speaking wrote on the chalkboard x + 2 = 4

13 T (Sahib without responding to student's (S1) response turns to other students)

Anyone in the class, tell me the meaning of 2x?

14 S2 (Another student who raised his hand) x plus x

The teacher ignores S2's response and invites another student to answer the question

15 S3 x multiplied by 2

16 T Good (as if teacher expected only correct textbook knowledge and hence acknowledges it but incorrect ones he ignored), if there is no sign between x and a number it means that there is a sign of multiplication.

The teacher wrote on the chalkboard in one of the corner, x * x = x2 and x + x = 2x

17 T In multiplication powers are added and in addition coefficients are added.

A similar segment of a science lesson is given in appendix 1.

From this point onwards the students remained silent, looking at each other…. looking confused… teacher went on talking…. 'telling' textbook explanations and imposing his own ideas onto the students without a single attempt to find out why students (S1, S2) responses were different from his expected (textbook) ones.

The teacher's inappropriate explanations, inadequate acknowledgement of students' responses and practically no attempt to seek for student explanations for their correct or incorrect responses had a negative impact on the students. Students became silent listeners and confused. As lines 16 and 17 reveal teacher himself had limited content knowledge that too was textbook knowledge. It was in the post-conference that the teacher realized that his knowledge was insufficient to understand the students' mathematical thinking processes and to analyze students' mathematical assumptions. The teacher was unable to extend students' ideas beyond textbook, to help them to formalize their intuitive thinking and challenge their incorrect notions to promote shared meaning of mathematical procedures. More importantly to make connections and meanings of own and new ideas with the textbook content. Not only Sahib but several other teachers we have worked with have revealed this concern.

Connection between new ideas and textbook content

The lack of teachers' mathematical understanding hindered them to make connections of new ideas with mathematical assumptions in the textbook procedures. These problems with mathematical knowledge acted as a barrier to teachers in linking their students' prior / former learning to the new concepts in the context of a lesson. The teachers often attempted to organise practical activities to teach for conceptual understanding but they could rarely incorporate any adequate explanations with reasoning within that chosen practical demonstration. Next we offer a case from our classroom observation that exemplifies this issue of teachers' inappropriate explanations.

The teacher [Sahib] introduced 'circles' through a practical demonstration. Sahib asked one student (Kamran: students sat on the floor, there were no student benches or chairs in the class) to stand up and stretch his arm, then the other students were asked to stand at a distance of Kamran's arm length; in this way he had the students to form a circle themselves with one student (Kamran) at the centre. Next he drew a circle on the chalkboard. He then asked students to imagine and identify their positions in the diagram on the chalkboard. From this moment onwards the teacher-students talk that followed is given below in the box.

1 T Now look at the board.

2 T What is the distance between Kamran and each student?

3 S (A voice from the class) about an arm.

4 T Where is Kamran[4]? (Kamran Kahaan hai ?)

5 S In the middle (Beech main).

6 T In 'English' [language] we call it [pointing at the centre] 'centre', and the distance between Kamran and each student is called 'radius'.

[4] Kamran was the student who was standing at the centre in the practical demonstration; therefore, the teacher asked them to imagine the position of Kamran.

The teacher next asked the students 'what will we call the distance between Kamran and each of you…'(repeated it three times). Students (in chorus each time) radius. He then joined two points on the circumference of the circle to form a chord and asked:

7 T When we join two points on a circle what do we call this distance?

8 S2 'radius',

9 S3 (Another voice) 'diameter'

10 T The line or distance that joins two points of a circle is called a 'chord'.

The teacher then drew another line segment this time passing through the centre of the circle and' told' the students this is the diameter that also joines two points on the circle. He then asked:

11 T What difference do you see between these two lines? (pointing to the chord and then the diameter: chord and diameter were free-hand drawings)

12 S4 One is straight and the other is slanting.

13 S5 One passes through the centre while the other does not.

14 T How many radii are in a diameter?

(no response from the students.)

15 T What is the difference between a diameter and a radius?

16 T If diameter is two then the radius is one.

17 T If diameter is 10, what will be the radius?

18 S6 Five.

19 T A diameter has always two radii.

The teacher then asked the students to draw circles and identify diameter, chord and radial [5] ***segment.***

The above example shows that the teacher did not use appropriate mathematical language in introducing the circle; for example, he seemed to be confused between the geometrical concepts of 'line segment' and the physical quantity 'distance' (e.g., line 10). He did not provide clear definitions of the terms that he used namely radius, radial segment, chord, and diameter. Neither did he explain clearly that he used the radius interchangeably to mean 'half length' of diameter as well as a 'line joining the centre to any point on the circumference'. The teacher found it difficult to integrate practical activities with the appropriate and mathematically accepted textbook explanations. We believe this was either because the teacher did not have

[5] According to the textbook a radial segment is a line which joins the centre to circumference and radius is the distance between the centre and circumference.

adequate mathematical knowledge to provide the students with a clear explanation about these terms or the teacher had inadequate competency in using practical activities.

DISCUSSION

The above examples uncover an issue of the teachers' inability to integrate informal and formal subject matter assumptions, ideas and procedures and the students' former learning experiences in order to promote students' concept building in the subject. The teachers' knowledge was based on textbook knowledge for which they did not have much conceptual understanding. The teachers' own lack of subject matter understanding did not allow them to promote a child-centred learning environment. They, primarily sustained their authority in the classroom and used traditional teaching methods contrary to what they intended to achieve.

A gap existed between the teachers' personal subject matter knowledge and what they expected of students' learning with reasoning to be. The teachers' beliefs and aims of teaching were updated by AKU-IED's influence but their inadequate subject matter understanding obstructed them to achieve their aims of the lessons. The teachers' new expectations of their teaching exacerbated the problem of their limited subject matter knowledge. The teachers seemed to be unable to re-conceptualise their teaching in the real classroom conditions in the context of their improvement in practice. All three teachers taught the lessons in fragments without establishing explicit connections or incorporating students' responses.

The issue of how teachers can develop new roles with their inadequate mathematics or science background needs to be addressed. How can teachers teach differently, if they have only memorized rules themselves? If the teachers' own experience of doing mathematics/science means following the teachers' rules or memorizing what teacher or textbook says, then how can they provide the experience of mathematics/science with reasoning without them knowing the reasoning themselves? Do the teachers have resources and support to advance their knowledge at the school level? What would be the consequences of the teacher's limited knowledge for the children's learning?

We suspect that the limitation of mathematics/science is a big threat to the teachers' confidence and desire for developing innovative teaching. In the context of a Pakistan school, mistakes are not accepted due to an expectation that focuses on the product and 'the what' instead of the process and 'the why'. For example, when a parent asked for clarification of the teacher's explanation (that was different from the textbook's explanation), the teacher felt threatened. The teacher reverted to the textbook and blamed the student's carelessness in listening to the teacher, because s/he wanted to avoid further complications and misjudgments. The teacher did not want to be dishonest but for his/her it had implications for his/her appraisal and his/her position at the school. The teacher's behavior reflects the context of Pakistan schools, where mistakes are not expected and accepted, particularly from professionals and elders. Our own background experience of living and teaching in Pakistan confirms that it is a matter of shame and threat to admit a lack in knowledge; it is highly embedded in the cultural norms of our context. As teachers make efforts to improve their teaching, they are likely to run a risk of being negatively viewed because it exposes their lack of knowledge and this will be seen as having a negative effect on students' learning outcomes.

Our analysis uncovers the issue that teachers cannot grow further professionally with their limited subject matter and pedagogical knowledge. The teachers need to enhance their mathematics/science understanding in order to understand what constitutes teaching of mathematics/science with reasoning. The teacher educators (in this case at AKU-IED) need to have a greater sensitivity to, and understanding of, the consequences of teachers' limited knowledge on students' learning as well as implementing the learning from a Visiting Teacher (currently called Education in Certificate: Mathematics or Science) programme. Should educators (in this case at AKU-IED) suggest that teaching directly from textbooks is more appropriate in the circumstances of limited understanding of mathematics and pedagogy? What implication has this for a future VT programme?

Our earlier discussion of the underlying philosophy of the teacher educators in Pakistan addresses[6] important issues in relation to development of teachers' mathematics/science teaching that supports school children's development of thinking capabilities. A traditional mode of teaching reduces children's cognitive and intelligent thinking and sustains the shortcomings in developing innovative teaching. However, the teachers appeared to be aware of the usefulness of the new methods of teaching and were motivated to improve their teaching. They also believed that to involve students in learning with reasoning is beneficial for students' development of thinking.

However, a transition from routine practice to a new perspective of teaching is not an easy task for the teachers in Pakistan. The teachers' own conceptual limitations restricted them in conceptualising the underlying assumptions of the philosophy of AKU-IED in the practicality of their new roles as teachers (Mohammad, 2005). The teachers were unable to explain the assumptions of their proposed new practice designed to help students develop conceptual thinking from a mathematics/science activity when they tried to implement their AKU-IED learning into the classroom. They had difficulties in engaging students in any problem solving method to enable students to generate their own ideas. The teachers were able to collect and include in their plans interesting activities, invite students' answers, organise group work, but they were unable to align such activities to the objectives of the lessons for conceptual understanding.

There are indicators in this study for AKU-IED that point to teachers' needs with which the teacher educators must be concerned. The teacher educators at AKU-IED (including

[6] Based on concepts such as learning with reasoning, encouraging students' participation in activity and thinking and organising the classroom for cooperative learning

ourselves) need to; review what teaching means in Pakistan schools; consider the people who will teach and their mathematics/science comprehension, and to improve the design and the delivery of the programmes.

Teachers cannot go further on their own with their limited understanding of mathematics /science subjects and mathematics/science teaching. They need to develop their own conceptual understanding first before they can make sense of students' thinking, handle their answers effectively and promote conceptual understanding (Mohammad, 2004).

Two major and crucial areas for the educators at AKU-IED to consider we feel are:

(a) Mathematics/Science Knowledge - teachers have very limited mathematics/science subject matter knowledge; they need to be taught mathematics/science. The Aga Khan University-Institute for Educational Development needs to address how, where, and when would teachers learn mathematics/science? What would be the consequences of teachers' limited mathematics/science in understanding of new ideology of learning presented at the AKU-IED?

(b) Mathematics/science Pedagogy - teachers do not appear to understand the values of teaching concepts such as negotiating, encouraging, participation. They do it, if at all; because AKU-IED said it was good. Where/when/how do they come to understand its value and need? Of course, (b) can be related to (a) but with regards to 'where/when/how' it needs to be addressed.

CONCLUSION

In this paper we have argued, with supporting evidences from Pakistan, for the need of sound subject matter knowledge of mathematics/science teachers to empower them to be more successful in implementing innovative teaching rather than in the struggle to revert to old practice. This, as the above literature review also suggests, resonates with the findings of other countries e.g. UK and USA. The issue, thus, is local as well as global. Currently, we feel the mathematics/science teacher education courses offered at the teacher education institutes predominantly address subject matter knowledge as a part of the over all discourse of the programme/course to deliver the new instructional theories, philosophies and pedagogy. As such the course time is always insufficient to cover all necessary content adequately. We feel there is urgent need for the teacher development institutes to provide alternate pathways to enhance teachers' (mathematics/science) subject matter knowledge. Possible alternatives can be: introduction of subject specialization courses that can allow teachers to study one or more subjects in depth. Another pathway can be establishment of University-School partnerships that can eventually lead to teachers' networking for on-going learning through 'communities of learners' (Pardhan and Rowell, 2005). In order to resolve teachers' issues related to subject matter knowledge, there is a need for 'communities of learners' at professional level among teachers who are committed to change their practices. Furthermore, teacher educators or teacher education reforms should not focus solely on strategies for the development of individuals but also promote ways and means where the individuals can work with colleagues and organisational leaders to impact learning outcomes.

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APPENDIX 1

The lesson began with recall of text-book definition of matter 'matter has mass and occupies space': (Key: S1, S2,…. Represents individual student; SS represent all students and PT represents the teacher)

PT Tell me what is matter?

S1 There are three states of matter

PT I have not asked about states…

S2 Miss, anything that is like stone.

PT (no response to the student S2's answer) Anything that has…. (expecting students to respond … students quiet or some talking) What it has … Sara, what it has… (no response from Sara) …Anything which has mass and occupies space … now say together…

PT and SS (in chorus) Anything that has mass and occupies space (repeat a couple of times).What are three states of matter?

SS (almost all in chorus) Solid, liquid and gas

PT (repeats) Solid, liquid and gas…can you give me example? (lesson transcript)

PT is at the chalk board, most of the time facing the chalkboard. Many voices … hard to hear anything distinctly, students at the back of the class near me [R] seen doing their own things…busy talking…PT writes on chalkboard: Solid Liquid Gas…walks to a student in front close by…(field observations and notes)

S3 Sui Gas (local name for methane gas used as energy source by most house holds)

PT Very good (goes back to chalkboard writes 'Sui Gas' under 'Gas' and writes some own examples under 'Solid' and 'Liquids' and then erases everything). (lesson transcript)

It is five minutes into the lesson… mostly teacher talks and that too fast and expects quick standard answers. Mostly students closer to teacher's table just in front of the classroom seen paying some attention rest doing own things… looking around, fidgeting, or just sitting idle…In similar manner, for the next seven minutes students are asked 'what' and 'when' questions about shopping apples and milk and teacher manages few students to say apples 'we buy in kilo' and 'milk in liters'. Simultaneously keeps writing and erasing on board. Finally makes two columns: kilogram/gram/milligram/pau and liter/milliliter as headings. Note 'pau' is a local unit for 100 grams. And then suddenly turns to the class and 'now I will give …you (students) will have to be careful…' leans over a table by the chalkboard, picks up plastic bags with stuff in … co-teacher who had been standing in the front left corner of the class all this time helps to pass the bags …teacher randomly gives away items (including sheets of paper to rite on) tied in plastic bags or loosely… students start talking, reaching for items or almost snatching items… some girls hold onto items for themselves…noise level goes up…teacher mostly stays in front of the class with one group in particular, facing away from the rest of the class …for the next fifteen to twenty minutes there is commotion in the class… most of the time students are unsure as to what to do or perhaps just seem to seek teachers consent. Students are heard asking questions but mostly low level 'what is this … thing? what to write? where to write this?' or reporting what the other student has written. Teacher responds now and then and that too by 'telling' rather than stimulating discussion. Teacher's questions are mostly low level 'what' 'where' type, though 'why' were heard at times, but these were inadequately capitalized upon for purposes of making students to think or get a satisfactory answer... (field observations and notes)

Students seemed to have difficulty in a) knowing what to do b) reading and writing words and c) understanding concepts. The student-teacher talk most of time was more like a guessing game as this transcript segment suggests: [Key: PT for teacher; S1, S2, ... for students]

PT (pointing at a student's work) this one here write 'coca cola' …what is this that you have written…(picks up a coca cola can)

S3 (pointing at a writing on the can) This here is its name

PT Read it

S3 Ko…kaa… ko…ka

S4 Teacher this (meaning the word coka cola) should come up here

(unlike most of the other students, this student had divided the page into two columns by drawing a straight line right across the middle of the page widthwise. 'Up' meant top have of the page …see appendix 6)

PT Why should it go up there?

PT (mixed voices of students…can only pick up some words …) ko…ka…teacher…ko… teacher…will go up (meaning top half of the page) …

PT Why would it be up?

S4 Teacher it has air… air is in it…

PT What comes in it?

S4 Yes, liquid comes in it.

PT Yes,

S3 Teacher solid…solid…Yes

S4 Gee…ram

PT Yes, it will come under 'gram'. Very good. (lesson transcript/ field notes: for sample transcript see Appendix 2)

Students' not knowing what to do lead to confusion and restlessness in class. The last ten minutes were mostly spent in teacher trying to manage class and in the process getting frustrated: Ten minutes to go for students' snack break to be followed by school recess… noise level has risen …materials are still on the tables or some on the floor…teacher is trying to get students' attention…it is not working… suddenly …(field observations/notes)

PT (almost shouting) Now girls…now girls…what have you written? Say your answers… (turns around faces the chalk board and the students sitting on her right in front…) under the column 'Kilogram/gram' ... (the students in front get all the attention and they contribute five items... rest of the students either moving around, talking or fighting … for the Litre/millilitre column teacher hurriedly entered five items herself without saying a word… it is only four minutes left for the lesson… in an angry loud voice) I want you all to stop…please bring all the things (only some students from the two groups in front responded and walked up to hand some items… co-teacher and teacher move around to collect items…trying to make students quieter and stay in their seats… students were getting restless…impatiently waiting for the bell to ring…). (lesson transcript/field notes)

Source: Pardhan, 2002: 62-65

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DO HIGH-SCHOOL STUDENTS' PERCEPTIONS OF SCIENCE CHANGE WHEN ADDRESSED DIRECTLY BY RESEARCHERS?

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ABSTRACT. The Universitй des Lycйens (University of High-School Students) was set up in France in order to make scientific knowledge more relevant to students and to combat a growing lack of interest in science among students. The scheme involves a series of lectures to students by scientists, each followed by a debate. The organisers hope that putting students in direct contact with researchers will motivate them and enable them to envisage the nature of science and careers in science in a different way. Each of the three lectures covered by this study focused on a socio-scientific issue. In spite of the socio-cultural differences observed, the students have a positive opinion of science, scientists and careers in science. But, in the meanwhile, they believe that scientific research may have negative effects. The lectures had little effect, either on their prior conceptions of science and scientists, nor on their acquisition of knowledge.

KEYWORDS. Nature of Science, Socio-Scientific Issues, Careers in Science.

FRAMEWORK AND PROBLEM

The Universitй des Lycйens (University of High-School Students) was set up in France by the Mission d'Animation des Agrobiosciences or MAA in order to make scientific knowledge more relevant to students and to combat a growing lack of interest in science among students. The scheme involves a series of lectures to students by scientists, each followed by a debate. The organisers hope that putting students in direct contact with researchers will motivate them and enable them to envisage the nature of science and careers in science in a different way.

For each session, the main speaker is a researcher. The researcher covers a scientific field based on his own individual experience but also on the collective experience in his field (i.e. evolution, challenges, constraints, motivation, issues under debate, among others).

The lecture is completed by another speaker from another field or professional sector, who reacts to the researcher's speech.

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Each lecture is delivered to between 200 and 400 students. Each of the three lectures covered by this study focused on a socio-scientific issue. They were entitled "Plants: miniature chemical factories", "What will tomorrow's climate be?" and "Can economics help Africa?". We analysed the effect of the first lecture on 136 students, that of the second on 177 students and that of the third on 287 students. All the students came from one of three main categories, general, technical or professional courses. There was a further difference concerning students in the general category, who came from either economics or science streams.

Conferences

The conference: "Plants: miniature chemical factories"

The lecturer had to deal with the following themes: Plant cells are capable of synthesizing tens of thousands of molecules including the most complex ones. How does this occur? What types of substances are produced in this way? The lecturer also had to cover the various ways plant cells are used by industry and their incredible potential which still has to be exploited, in particular for research in the fight against cancer.

Some comments by the authors on this lecture

The lecturer, after having developed the theme described above, illustrated it by means of two applications which are exemplary of plant biotechnology, which is the lecturer's field of research: the production of golden rice enriched with vitamin A, and the production of gastric lipase to combat the symptoms of cystic fibrosis.

The development of plant biotechnology led to debates as to the their repercussions. These are controversial issues. We shall describe their definition below. In our opinion, the teaching of plant biotechnology involves a new challenge as it requires training informed people who are capable of taking well-founded decisions in spite of the uncertainty and of participating in social debates on the development in question. As indicated by Legardez, teachers, when confronted with socially controversial scientific issues, sometimes try to 'cool them down'. We wonder whether this was not the case here. A controversial or 'hot' body of knowledge such as the production of genetically modified plants was dealt with here in a diplomatic or 'cooled down' way during the lecture. The lecturer moreover refused to answer questions on GMOs.

The scientific content of the lecture was very challenging.

The conference: "What will tomorrow's climate be?"

The lecturer had to deal with the following themes: Which climatic changes may occur between 50 and 100 years from now? Is the planet actually heating up? Once again, this led to a debate on scientific knowledge. What is the status of our current knowledge on this issue, the tendencies and different scenarios, the consequences on the level of the oceans, snow fields in mountains, agriculture, water reserves? What should be done to fight this trend and at what cost?

Some of the authors' comments on this lecture

The lecturer gave a fairly 'didactic' lecture on weather forecasting and its limits on climatology, on how the greenhouse effect functions and why it is necessary and on the causes of global warming while only considering the extent of global warming and not whether it was a reality. It should be said that there is a debate today concerning the 'hockey stickcurve', which is a symbol of planetary warming and which was published in Nature in 1998. Among the means being considered to fight the consequences of global warming on agriculture, the speaker described the development of transgenic plants capable of resisting drought.

The conference: "Can economics help Africa?"

The lecturer had to deal with the following themes: Economic science is not only useful to developed countries, but can also help poor countries to develop and lay the basis for peace on condition that it be adapted to the reality of those countries, since not all economic recipes are suitable for all countries. How much does it cost to develop the economies of poor countries and how can economics help prevent civil wars in Black Africa?

Some of the authors' comments on this lecture

This lecture stood out due to the 'friendly' personality of the speaker. He dealt with the use of mathematics in economics but also the importance of field surveys.

Socio-scientific issues

One of the goals of science education is to help students develop their understanding of how society and science are mutually dependent. This is the educational school of thought known as 'Science-Technology-Society' (STS) and it includes the study of controversial scientific issues. These issues lead to debates on the production of reference knowledge; they are omnipresent in the social and media environment.

In science education the notion of 'socio-scientific issues' has been introduced as a way of describing social dilemmas impinging on scientific fields (Gayford, 2002; Kolstoe, 2001; Sadler et al., 2004; Zeidler et al. 2002, Yang, 2005, Patronis et al., 1999…). These are issues on which people have different opinions and which have implications in one or more of the following fields: biology, sociology, ethics, politics, economics and/or the environment. Socio-scientific issues are controversial since they are intrinsically unpredictable.

The educational challenge is to enable students to develop informed opinions on these issues, to be capable of making choices with respect to preventive measures and to intelligent use of new techniques and especially to be able to debate such issues. This means, among other requirements, that students have to understand the scientific content involved, including the epistemology and that they must be able to identify controversial topics and analyse their social implications (in economic, political and ethical terms, etc.). A person whose is 'literate' in science should be able to understand and participate in debates on 'socio-scientific" issues. In order to solve most problems arising in modern society, scientific solutions alone are not enough, in other words, they must also take into account the social implications of decisions relating to scientific investigation (Sadler et al., 2004 a & b ; Zeidler et al. 2002).

Given the increasing importance of many socio-scientific issues (biotechnology, environmental problems, etc.) in modern society, each student is already having to or will have to make decisions on such issues and schools should thus help them prepare to be informed citizens.

As named by Edgar Morin (1998), the issue raised is 'an historical and henceforth crucial problem of cognitive democracy'. Socio-biological issues, in Edgar Morin's terms, are 'polydisciplinary', multidimensional, transnational and in a context of increasing globalisation, planetary in nature. We believe that this didactic approach fits Edgar Morin's analysis well in that it is education based on 'the necessity of reinforcing critical thinking by linking knowledge to doubt, by integrating particular knowledge in a global context and using it in real life, by developing individuals' ability to deal with fundamental problems with which they are confronted in their own historical epoch'.

Conceptions of science, science education and the scientific professions

We based our investigative method on various research projects carried out at an international level on students' attitudes to science. This research highlighted the influence of various factors such as gender, school curricula, culture, etc. This issue was discussed in an excellent literary review published in September 2003 by Osborne et al.

A set of behavioural characteristics leading to a generally positive attitude to science was classified as follows:

- the manifestation of favourable attitudes towards science and scientists;
- the acceptance of scientific inquiry as a way of thought;
- the adoption of 'scientific attitudes';
- the enjoyment of science learning experiences;
- the development of interests in science and science-related activities; and
- the development of an interest in pursuing a career in science or science related work. Klopfer (1971)

Several studies (Breakwell & Beardsell, 1992 ; Brown, 1976 ; Crawley & Black, 1992 ; Gardner, 1975 ; Haladyna, Olsen & Shaughnessy, 1982 ; Keys, 1987 ; Koballa, 1995 ; Oliver & Simpson, 1988 ; Ormerod & Duckworth, 1975 ; Piburn, 1993 ; Talton & Simpson, 1985, 1986, 1987 ; Woolnough, 1994) have incorporated a range of components in their measures of attitudes to science including:

- the perception of the science teachers;
- anxiety toward science;
- the value of science;
- motivation towards science;
- enjoyment of science;
- attitudes of peers and friends towards science;
- the nature of the classroom environment;
- achievement in science; and
- fear of failure on course.

It should be noted that students may express their interest in science while not doing so when in the company of other students who do not share this interest. Adolescents are strongly influenced by group norms. Thus, Head (1985) considers that adolescence is a moratorium period during which the development of the personality is suspended and thus affected more by normative peer group expectations. For instance, it seems to be 'normal' for boys to study science and not for girls. Conforming is thus a way of establishing gender identity.

A distinction should be made between students' attitudes towards science and towards the learning of science. For instance, Whitfield (1980) and Ormerod (1971) asked students to classify their interest in different school disciplines. We followed their example by adding a question on the fear of failure in the various disciplines.

Recent research was undertaken on the relationship between attitude towards scientific disciplines and students' achievements in 3 countries (Australia, Cyprus, USA) (Papanastasiou & Zembylas, 2004). A computer model was built to analyse this correlation. The variables taken into account are the individuals' perception of competence and individuals' inclination to study biology, Earth sciences, physics and chemistry and the significance attached by fathers, mothers, friends and the individuals themselves to their achievements in scientific disciplines.

The research mentioned above demonstrates that environmental factors do influence students' attitudes to science, particularly their socio-economic background, enjoyment of science learning, fear of failure, extra-curricular activities (especially those carried out with the student's father), childhood experiences (e.g.: use of introductory science kits and games) and the attitudes of peers and friends. Is this also true for our sample group of students?

In society, science education specialists are increasingly studying the nature of science and the interdependence of society and science (Sadler et al, 2004). The consensus on the nature of science is as follows: some scientific knowledge is relatively stable while other knowledge is more provisional and likely to change according to new results or because previous results have been reinterpreted (Harding & Hare, 2000). Science is based on empirical proof and scientists use their creativity to obtain and interpret this proof. Scientific research and cultural norms mutually influence each other (Sadler et al., 2004). Knowledge of the nature of science affects the analysis of socio-scientific issues. In order to be able to deal with this type of issue, students have to know how to recognize and interpret data, to understand how different social factors can have different effects and to understand that stakeholders often have diverging opinions (Sadler et al., 2004). How do our sample students perceive the nature of science? What are the students' views on the interactions between science and society? Which factors affect scientific research? Does scientific research have an impact on society? If so, what kind of impact?

It should not be forgotten that attitude is a lasting quality whereas knowledge is ephemeral (Osborne, Simon & Collins, 2003, Simonneaux, 1995).

One criticism which could be made is that the methods used for measuring opinion only see the tip of the iceberg. These methods were therefore supplemented by a series of semi-directive interviews, in order to identify and better understand the students' opinions and their origins.

METHODS

We evaluated the amount of scientific knowledge acquired by students concerning subjects discussed in lectures and the subsequent effect on their perceptions of science, science education and the scientific and technological professions. This process entailed several phases:

- Interviews with the lecturers for the purpose of drawing up a thematic questionnaire,

- Prior to the lecture, completion of a questionnaire on what science, science education and the scientific and technological professions meant to the students. This questionnaire was supplemented by thematic questions aimed at establishing how much the students already knew about the subject of the lecture.

- After the lecture, completion of a second questionnaire designed to measure changes in viewpoints and knowledge acquired on the subject.

- In-depth interviews with a sample group of students.

In this paper, we mainly describe the results of the lectures on students' perceptions of science, scientific teaching and scientific professions.

FINDINGS

What do high-school students think of scientific studies and school disciplines?

The pre and post test questionnaires described in this section included in all 27 questions, 18 of which referred mostly to the socio-cultural characteristics of high-school students, to the projects with respect to training and profession, to their inclinations and fear of failure with respect to courses in different disciplines and to their informal, extracurricular scientific activities. The answers to these questions should not vary significantly after the lecture and should enable us to check the reliability of the questionnaire.

The 9 other questions concerned their opinion of scientists, the usefulness of scientific research for society, their feelings about the development of research, the goals and possible risks involved in scientific research, the products of scientific disciplines and factors which influence research and researchers.

Students' socio-cultural characteristics

The extent to which the study course taken depended on the father's profession is very significant. High school students in courses which are supposed to lead to science studies tend to come from well-off families. This leads to the disquieting question: Can school act as a social elevator or does it simply reinforce social reproduction?

Students on science courses tend to also have friends who are considering careers in science[1] (VS). This is consistent with other results demonstrating the influence of peers' and friends' opinions of science. They also receive more encouragement from their parents to undertake scientific studies (S).

Thirty-four point three percent of students consider taking scientific studies and 44.6% do not intend doing so.

The dependency between classes and training projects was found to be very significant: for the S-stream (science) students alone, more than 70% are considering scientific studies for their future, whereas 70 to 100% of students in economics, technological and professional streams, are not.

Enjoyment and fear of failure with regard to different subjects

Most of the students in the sample population liked the various subjects. Enjoyment can come from various sources: pleasure in studying the subject, the quality of the teaching, the marks obtained, etc.

More than 27% of the students said they enjoyed their biology courses 'a lot' and '57%' liked them 'quite a lot'. The dependency between classes and inclination was very significant:

[1]NS = non significant dependence; S = significant dependence; VS = very significant dependence.

economics-stream students were the least enthusiastic, with more than 21% claiming that they do not like biology 'at all' (as against 4% for the overall sample population). More than 50% of S-stream students liked biology 'a lot'.

Let us now consider the answers for which the percentages are the highest:

- fifty-five percent of the students liked the geography course 'quite a lot' (25% of S-stream 'did not like it' as opposed to 12% for the overall sample population (VS)).
- fifty percent liked their history class 'quite a lot'.
- forty-eight percent liked their mathematics class 'quite a lot' (VS).
- forty-five percent liked their physics class 'quite a lot' (VS).
- it is logical that 70% of the economics-stream students like economics 'quite a lot'.
- forty-six point six percent of the students liked chemistry classes 'quite a lot' (VS). More than 30% of students in a professional stream 'did not like' chemistry (as opposed to 13% for the overall sample population) and 31% of economics-stream students 'did not like' chemistry at all' (as opposed to 7% for the overall sample population).

And 85% of students liked doing practical work.

Concerning the fear of failure:

- 45.8% were not afraid of failure in biology (S),
- 55% were not afraid of failure in geography,
- 48.3% were not afraid of failure in history (VS),
- 49.5% were afraid of failure in mathematics (VS),
- 50.9% were afraid of failure in physics (VS),
- 42.4% were afraid of failure in chemistry (VS).

Obviously, the more individuals are faced directly with tests in the various subjects, the more afraid they are of failure. No change in opinion was noted between pre- and post-testing, which confirms the internal validity of the study.

Does the study of science make students intelligent? Is it easy to study science? Does the study of science help find a job?

Sixty-seven point seven percent of the individuals believed that studying science in high school does not make them more intelligent than when they study other disciplines (VS). 43.8% believed that studying science is neither easy nor difficult; 2.4% believed that it is very easy, 10% that it is easy, 35.3% that it is difficult and 8.9% that it is very difficult (there was a very significant dependency between classes, in particular 27,3% of students in the professional stream believed that it is very difficult).

Forty-one point three percent believed that scientific training would help them to find work; 32% did not know. The dependency was very significant between classes: about 60% of students in the S-stream and 54% in the first year of high school believed this to be true. Almost 35% believed that studying science at high school would help them solve problems of daily life and more than 27% believed that it would not help them more than the study of other disciplines (VS).

What do they think of scientists and scientific research?

Overall, the students' opinions of the scientists and of the value of scientific research were found to be positive. 55.3 % had a favourable opinion of the scientists; 61.7 % considered that scientific research is beneficial to society; 32.2 % were enthusiastic about progress in scientific research; 41.8 % were neither concerned nor enthusiastic and 18.7 % were concerned. Students in science courses were the most positive (VS), except for those who were considering careers in the environmental sciences, who were the most anxious with regard to progress in scientific research.

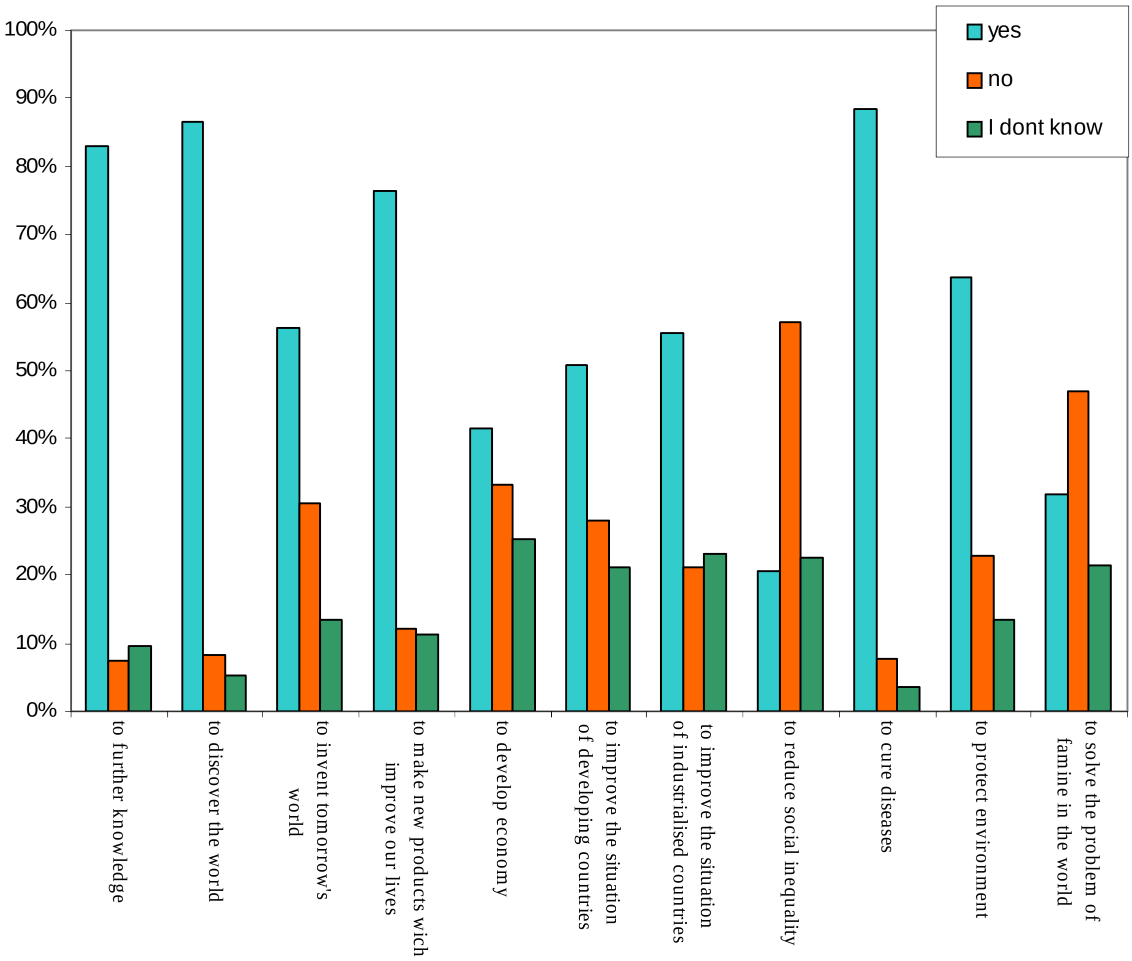


Table 1: Scientific research helps to

Most of the students affirmed (the ranking is in a decreasing order) that scientific research helps:

- to cure diseases (88.4%) (TS),

- to discover the world (86.5%),

- to further knowledge (83%), to make new products which improve our lives (76.5%) (TS),

- to protect the environment (63.7%) (S),

- to invent tomorrow's world (56.2%) (S) (more than 76% of S students believed this to be true and more than 63% of students in professional streams did not),

- to improve the situation of industrialised countries (55.6%),

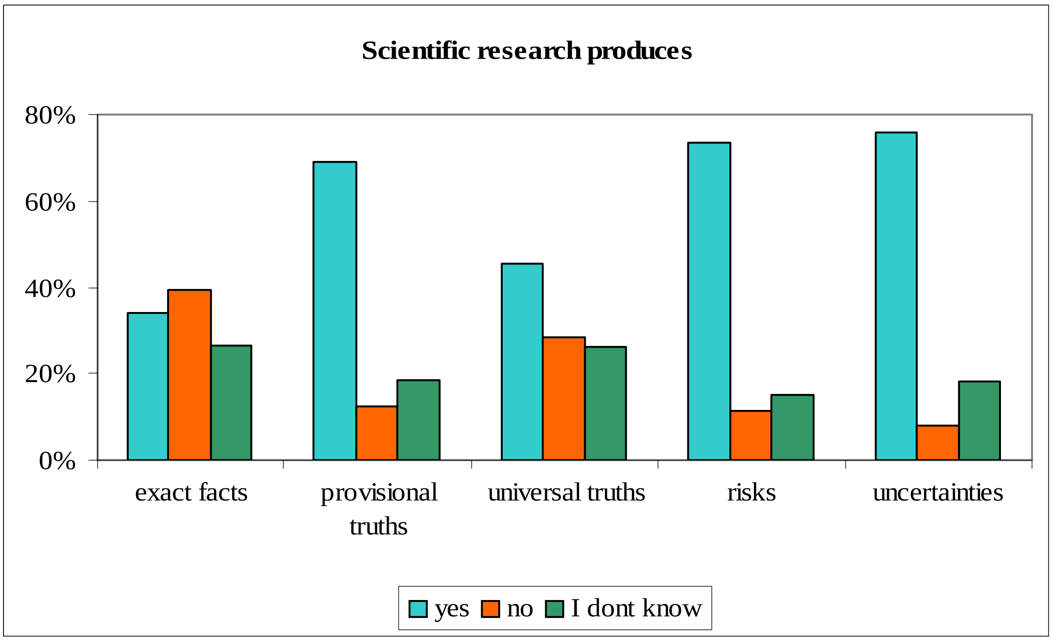
- to improve the situation of developing countries (50.7%).

On the contrary they:

- did not believe that scientific research could reduce social inequality (57.1%)

- nor that it could solve the problem of famine in the world (46.9%).

Table 2 : Scientific research produces



Most of the students rightly considered that scientific research produces provisional truth. They were less sure of themselves concerning the production of exact facts (26.5% said they didn't know) and universal truths (26.3% said they didn't know), perhaps because they had not clearly defined for themselves what universal truths are? Seventy three point six percent believed that scientific research produces risks and 75.7% that it produces uncertainties.

This raises the question as to which uncertainties are they referring to, uncertain knowledge or uncertain applications of such knowledge?

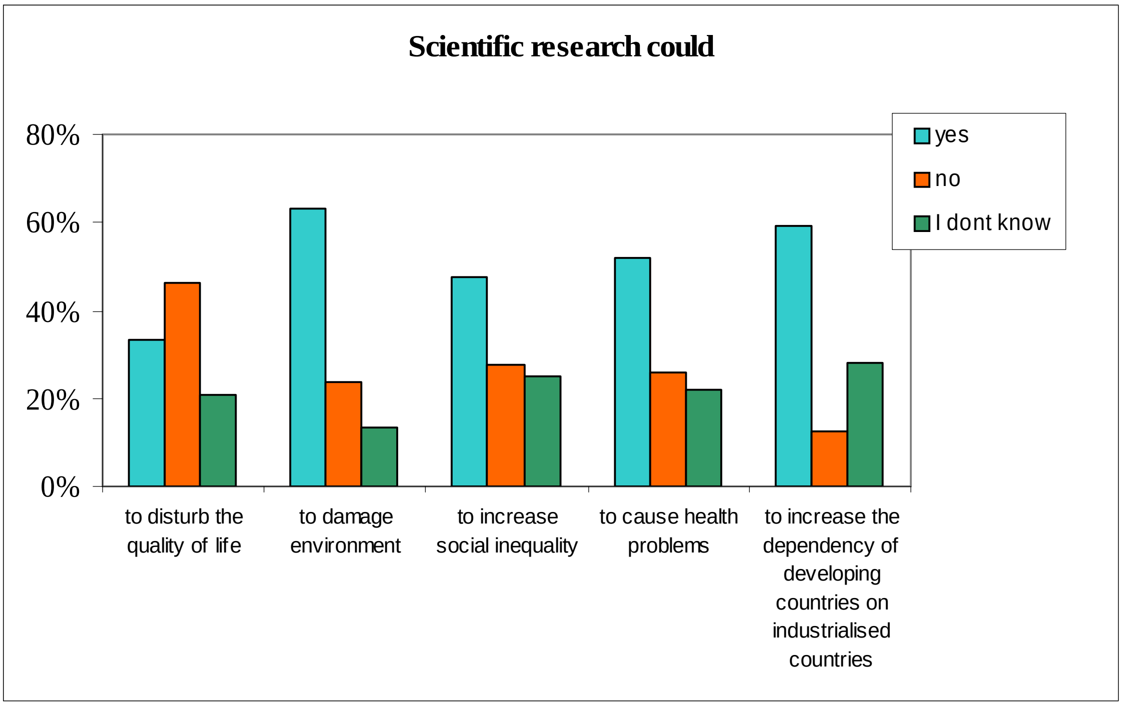


Table 3: Scientific research could

Forty six point one percent of the individuals did not think that scientific research could disturb the quality of life (though 60% of the technology students specialising in rural planning and development did think so while 20% of students in the second year of high school did not). On the contrary 63% believed that scientific research could damage the environment (but only 34% of students in the second year of high school). A majority of 59.4% of the students believed that it would increase the dependency of developing countries on industrialised countries (more than 70% of S students held that opinion). More than 52% believed that scientific research could cause health problems, 47.4% that it could increase social inequality (however 24.9% did not know what to think of that issue) and 52% of the students in the second year of high school did not believe that to be true.

What does research depend on?

In answering that question, 45.4% considered that it depends on the **moral values of the scientists** (32.3% did not know what to answer) (TS).

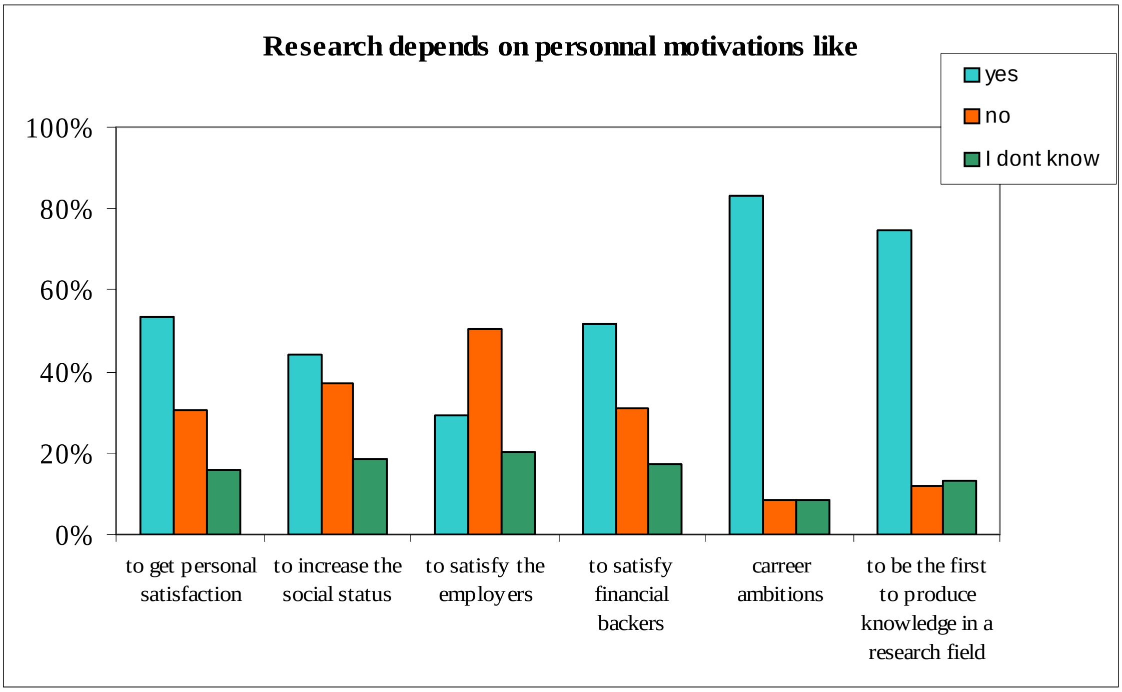


Table 4 : Research depends on personal motivations like

These students believed that researchers' career ambitions and wanting to be the first to produce knowledge in their research field were personal motivations which affected the outcome of research. Other factors, according to them, included satisfying financial backers and getting personal satisfaction out of their work. Half of the students thought that satisfying the employers was not a relevant factor. Opinions were similar irrespective of the training streams concerned.

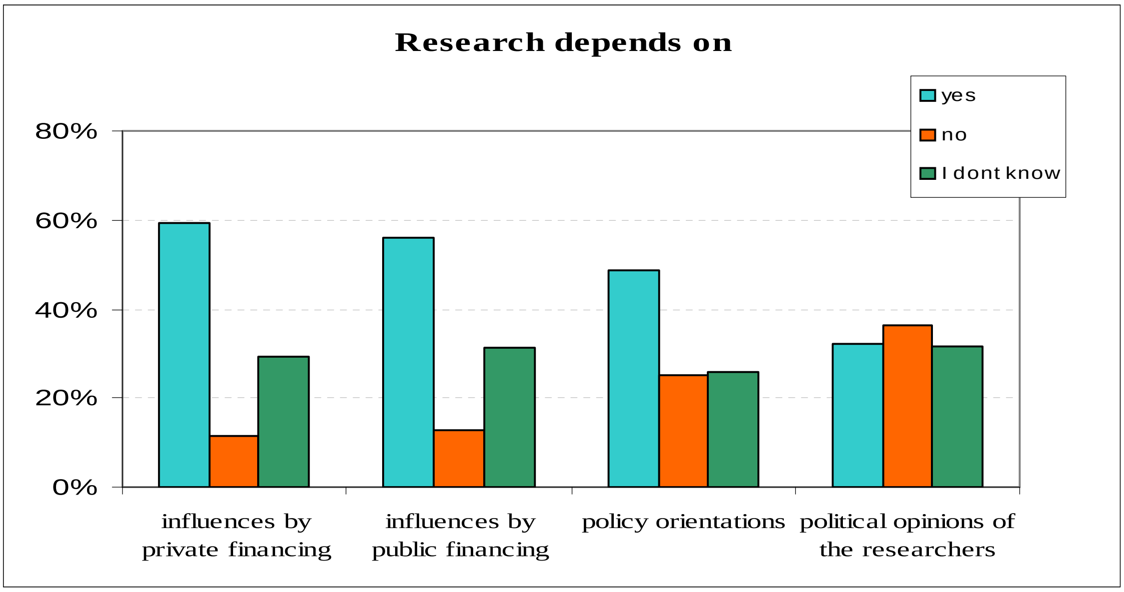


Table 5 : Research depends on

Fifty nine point two percent of the students believed that research is influenced by private financing (TS); more than 70% of S students agreed with that as opposed to 31% of students in the second year of high school; fifty-six point two percent believed that research is influenced by public financing (TS) and 31.2% admitted that they had no idea.

Forty eight point eight percent believed that research depends on policy orientations, while 25.3% did not believe this to be true and 25.9% did not know what to think (TS).

Thirty two point one percent did not think that it depends on the political opinions of the researchers, while 36.3% thought the contrary and 31.6% said that they did not know (S).

The possible impact of lecture-debates on what high school students think or know

It should be pointed out that only a few students took part in the debates (it is not easy to ask questions in an amphitheatre in front of students that you do not know), which is no indication of the relative contribution of the debates and the lectures on the students' knowledge-representation system. This system is a sum of social representations, residues from previous teaching and information conveyed by the media on the themes under discussion.

If we take an overall look at students who participated in the three lectures, we see that there was very little impact on their systems of knowledge representation, in particular on the adoption of scientific knowledge. Fewer of them believed that research helps to protect the environment (63.8% for the pre-test as opposed to 54.4% for the post-test). Does this mean that the high school students' university programme had no impact on high school students' perceptions of research? No.

We thus wanted to analyse the impact as a function of lectures which might be related to the theme, to the lecturer's delivery, but also to the fact that classes from different streams took part in them.

Fewer high school students believed that studying science in high school would help them solve problems of daily life (34.8% thought so during the pre-test, 27.4% during the post-test); it was especially those who attended the lecture on 'Plants' who changed their opinion (50% during the pre-test as against 32.7% for the post-test). And fewer of them were enthusiastic about the development of research (32.1% during the pre-test as opposed to 27.1% for the post-test), here again, it was mainly those who took part in the 'Plants' lecture who changed their mind (50.7% for the pre-test 37.2% for the post-test).

Of those high school students who attended the 'Africa' lecture, more of them thought that scientific research helped to develop economic growth (48.2% for the pre-test as against 56.5% for the post-test) and the dependency was very significant between the different lectures. There were also more of them who thought that scientific research helped to abolish social inequality (26 .6% for the pre-test as against 44.2% for the post-test); the dependency was very significant between the different lectures. Once again, more of them thought that research helped to reduce problems of famine in the world (31.9% for the pre-test as against 43.9% for the post-test), the dependency was significant between the different lectures.

Nor did the results vary for the products of scientific research (exact facts, temporary hypotheses, universal truths, risk and uncertainty) or with respect to disturbances that they might cause (deterioration of the quality of life, deterioration of the environment, increasing of social inequality, generation of human health problems, increasing dependency of developing countries on industrialised countries).

A few more of them thought that research depends on the personal motivations of researchers, such as enjoying their work (53.6% for the pre-test as against 60.6% for the post-test). Students who attended the 'Plants' lecture changed their minds more often (58.1% for the pre-test as against 72.5% for the post-test). There were also slightly more of them who believed that research depends on the personal motivations of researchers such as reinforcing their social status (44.2% for the pre-test as against 45.7% for the post-test). Once again, it was those who attended the 'Plants' lecture who changed their minds most often (41.,9% for the pre-test as against 56.5% for the post-test).

Was there a gender effect? Yes, for many variables

The dependency was very significant between gender and

- the fact of considering undertaking scientific studies: 43% of the girls as opposed to 29% of the boys.
- the idea that studying science in high school makes you more intelligent: fewer girls thought this was the case.
- inclination for geography classes: 23% of the girls did 'not like or not at all' as opposed to 10% of the boys.
- inclination for French classes: girls appreciated them much more.
- inclination for philosophy classes: 26% of the boys did 'not like them at all' as opposed to 9.4% of girls.
- inclination for physics classes: more than 24% of the girls did 'not like them' as opposed to 11.7% of the boys.
- inclination for economics classes: 23% of the girls did 'not like them' as opposed to 10% of the boys.
- inclination for language classes: 21% of the girls liked them 'a lot' as opposed to 8% of the boys.

The dependency was significant between gender and

- inclination for chemistry classes: more girls liked them than boys.

The dependency was very significant between gender and

- the fear of failure in French: the girls were less afraid.
- the fear of failure in mathematics: more than 60% of the girls were afraid as opposed to 42% of the boys.
- the fear of failure in physics: more than 63% of the girls were afraid as opposed to 42% of the boys.

The dependency was significant between gender and

- the fear of failure in languages: the girls were less afraid.

The dependency was very significant between gender and

- the fact of having friends who are considering a scientific career: girls have more friends who were considering doing so.

More girls are encouraged by their parents to do scientific studies than boys (S).

Fewer girls believed that research leads to exact facts (VS) and more girls believed that it produces temporary truths (VS).

After the lectures, more girls believed that studying science in high school would not help them more than other disciplines to solve problems in their daily lives (VS). More boys believed that research helps to improve the situation of industrialised countries (S), to reduce social inequalities (S).

Forty-five percent of the girls believed that studying science was difficult as opposed to 27% of the boys (VS).

More boys thought that research could deteriorate the quality of life (VS). The boys were also more numerous in believing that research depends on the personal motivation of scientists such as increasing their social status (S), pleasing their employers (S), pleasing the organisations that fund research (VS). Whereas more girls thought that research depends on influence due to public financing (S).

What is the social relevance of research related to?

A very significant dependency was found between the **positive** influence that high school students believe scientific research has on society and their positive opinion of scientists, the fact that research helps to improve the situation of developing countries, to invent a model for the future, to discover the world in which we live, to make new products which improve the quality of life, to improve the situation of industrialised countries, to heal serious illnesses and to protect the environment.

Conversely, those who believed that research has a **negative** effect on society believe that it can deteriorate the quality of life (VS).

The dependency was very significant between the **positive** influence that high school students believe scientific research has for society and the fact that their parents encouraged them to study science, the reading of scientifically oriented magazines and their inclination to watch a science TV programme.

The dependency was significant between the fact that high school students believe that scientific research is useful for society and the idea that it is easy to study science, if research is not influenced by public financing.

What is the decision to study science related to?

The dependency was found to be very significant between the orientation considered for scientific studies and believing that following a scientific career would help them to find work, believing that science studies are easy, encouragement from parents, the fact that friends are also considering a scientific career, that they like classes in chemistry, economics, physics, mathematics, biology, and that they believe that studying science in high school would help them to solve problems in their daily lives.

The decision to study science depends in a very significant way on the positive opinion that high school students have of scientists, of the relevance of research for society, of their feelings (enthusiasm) in relation to the development of research, to the fact that they believe that research does not depend on the political opinion of researchers, is not influenced by public financing, and to the fact that they think that research helps to protect the environment, to heal serious illnesses, to make new products which improve the quality of life.

The dependency was significant between the orientation envisaged for science studies and believing that study of science in high school makes one intelligent, believing that research helps to improve the situation of industrialised countries, to discover the world in which we live and that research does not depend on political orientations.

Which factors influence their feelings in relation to the development of research?

Students were more or less anxious or enthusiastic about the development of research according to social characteristics, such as the father's (S) or mother's (VS) profession, the encouragement of parents (VS) and according to many points of view: the opinion of scientists (VS), the usefulness of research for society (VS), the outlook for undertaking science studies (VS) or becoming a researcher (VS), the idea that undertaking a scientific career would help to find work (VS).

It also depended on their inclination for biology (VS), mathematics (S), physics (VS), chemistry (VS), practical work (S) for enthusiastic students; for history (S), philosophy (VS), economics (S), languages (VS) for anxious students. Consequently, those who liked social science were more anxious about the development of research than those who liked purely scientific disciplines and vice versa. This was not only related to students' training streams. The sample population did not include many high school students in human science streams (economics stream students). The most anxious believed that studying science is very difficult (S) and they do not read scientifically oriented magazines (VS).

This variable was also highly related, positively for enthusiastic students and negatively for anxious students, to the idea that research is useful for inventing tomorrow's world (VS), for making new products which improve the quality of life (VS), for improving the situation of developing countries (S), for improving the situation of developed countries (S), for reducing famine in the world (VS), for healing serious illnesses (VS) and for protecting the environment (S). Anxious students believed that research may deteriorate the quality of life (VS), the environment (VS), may increase social inequality (VS), may cause human health problems (VS).

Finally, this feeling of anxiety or enthusiasm was significantly dependent on the idea that research depends or not on the political opinions of researchers.

CONCLUSIONS AND IMPLICATIONS

In spite of the socio-cultural differences observed, the students have a positive opinion of science, scientists and careers in science.

The lectures had little effect, either on their prior conceptions of science and scientists, nor on their acquisition of knowledge. Thus, during the interviews, they declared that the level of the lecture was too high for them and that the lecturer talked too quickly during the 'Plants' lecture. If the experiment were to be repeated, it would perhaps be better to identify the students' system of representation and knowledge and then to define a learning base on which to build a teaching strategy, with the help of the lecturers, centred on the questions and concerns of the students and on their potential for learning and memorising. Students acquire new knowledge on socio-scientific issues via their system of representation and knowledge, i.e.: from their own social interpretation of the subject being studied. This may lead to negative or positive opinions which can stimulate or obstruct learning or their perceptions of science or scientists. Knowledge is also acquired via their previous scientific knowledge of the fields studied (information which may be incomplete, correct, or erroneous). In addition, we must not forget that the students' system of representation and knowledge is also affected by the media.

Although teachers were provided with a list of websites covering the same subjects as the lectures, the students were not assigned any preparatory work. More operational teaching aids should perhaps be created. We feel that the lectures would be of more value if they were incorporated into an overall teaching strategy, integrating both pre- and post-lecture activities, carried out in cooperation with the teaching staff. Knowledge is acquired more effectively when the method is multi episodic, i.e.: when knowledge is drawn upon at different times and in different contexts.

Finally, one last essential point needs to be made. In the lectures/debates, the students all found themselves (apart from the few who took part in the debate) in a transmission/reception scenario, corresponding to a teaching model in which they played a passive role. This observation confirms the idea that it would perhaps be better to integrate the lecture/debate into an overall teaching approach, which would enable the students to participate more actively.

The direct account of a researcher may in theory impress students. In a way, in this study we did not find that effect to be very great. But nevertheless, for socio-scientific issues, knowledge is not stable and sometimes controversial. Research itself is debated by citizens who may be researchers and who discuss its consequences. Is a researcher able to 'objectively' describe contradictory points of view? It is an illusion to believe that anyone is neutral on these issues. Furthermore, as we said above, most of the problems encountered in modern society require more than a scientific solution to solve them.

The educational challenge is to empower students so that they can contribute to the societal debates en socio-scientific issues. They must be able to identify the validity of the arguments of scientists, journalists, teachers, theirs as well as those held by other students, their value system, to understand the nature of science…

The students' line of reasoning is largely shaped by the media or their social milieu. Our intention is to get them to distance themselves from adopted arguments by encouraging them to think for themselves by analysing the information available and then to express their own thoughts on the matter. Apart from this, argumentation is an intrinsic part of learning as knowledge is gradually developed through informed debate.

The aim must be to help students to identify the criteria and information which support a point of view, , so that they can treat the issue as problematic. The most effective means of meeting this objective is discussion (in the generic sense). On condition that there are not too many participants in the debate, that each one be encouraged to participate and that the debates be based on information and content whose limits should be defined.

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WORKING WITH FUNCTIONS WITHOUT UNDERSTANDING: AN ASSESSMENT OF THE PERCEPTIONS OF BASOTHO COLLEGE MATHEMATICS SPECIALISTS ON THE IDEA OF' FUNCTION

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ABSTRACT. It is a well-known fact that the idea of function plays a unifying role in the development of mathematical concepts. Yet research has shown that many students do not understand it adequately even though they have experienced a great deal of success in performing a plethora of operations on function, and on using functions to solve various types of problems. This paper will report about an assessment of the perceptions of Basotho college mathematics specialists on the notion of function. Four hundred and ninety one (491) mathematics specialists enrolled at the National University of Lesotho (Years 1 - 4) in the 2002/2003 academic year responded to the questionnaire that challenged them, amongst other things, to (a) define a function, (b) give an example of a function, and (b) distinguish between functional and non-functional situations embedded in a variety of contexts. In addition to the difficulties observed in their attempt to define a function and to provide an example of a function, results suggests that, for the majority of those who responded to the questionnaire, the idea of function seemed to be limited to common or prototypical linear and quadratic situations that could be expressed either in symbolic or graphical forms. Additionally, arbitrary correspondences and functional situations that were presented implicitly were not identified as functions by the majority of the students. This paper discusses instructional, curricular, and research implications of the findings.

KEYWORDS. Concept, Assessment, Function, Mathematics.

INTRODUCTION

The idea of function plays an important role in the development of mathematical concepts in that it cuts across a range of mathematics content domains including those of algebra and geometry (National Council of Teachers of Mathematics (NCTM), 2000). However, research on students' understanding functions (e.g. Tall, 1996; Markovits et al. 1988) has shown that it is one of the least understood topics. A common definition of function is that of a correspondence that associates with each element in the first set a unique element in the second set. Some of the research (e.g. Vinner, 1992, Clement, 2001) has examined the extent to which one's concept image of function is consistent with the modern mathematical definition of function. According to Vinner, a person's concept image consists of all the mental pictures and perceptions that he or

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she constructs as a result of having interacted with the concept over an extended period. Research on the relationship between one concept image and definition has revealed some serious discrepancies. For instance, Clement (2001) observes that documented students' concept images of function include (a) tendency to regard a function as something that can be defined in terms of a simple rule, (b) relation whose graph is continuous, and (c) a relation that is one-to-one. The foregoing is clearly a very narrow conception of function, given that some functions can neither be represented in the form of a symbolic rule nor in the form of a graph. Moreover, some functions are not continuous, and others are onto.

Although most of the research work on students' understanding of function conducted in English-speaking cultures of the world (e.g. Markovits et al., 1988; Tall, 1996) has accumulated a useful body of knowledge pertaining to students' difficulties, conceptions, and definitions of function, little similar work has been done in non-English-speaking cultures of the world such as that of Lesotho in Southern Africa. Furthermore, to improve students' understanding of function, there is a need to develop detailed accounts of how they develop increasingly sophisticated ideas associated with function in an instructional setting. Accordingly, as a preliminary survey designed to collect baseline information, this study explored Basotho university mathematics specialists' understanding of function. More specifically, this study sought to explore students' ability to: (a) define a function, (b) provide an example of function, and (c) distinguish between functional and non-functional situations presented in symbolic and graphical forms, and (d) distinguish between functional and non-functional situations that are defined either implicitly or as arbitrary correspondences. It was hoped that the information thus generated, would, amongst other things, provide a basis for developing and testing instructional programmes that are capable of moving students from lower to higher levels of understanding the notion of function.

Theoretical Considerations

This paper is grounded on the assumption mathematical understanding is a complex and multi-faceted phenomenon. Consistent with this line of thinking, Kaput (1989) identifies two sources of conceptual understanding in mathematics: (a) referential extension which refers to the ability to make translations between mathematical representations, and to make translations between mathematical and non-mathematical situations, and (b) consolidation which refers to the ability to operate within a system, recognizing the pattern and syntax of the system, and building conceptual entities via reifying actions and procedures. In unpacking referential extension in the context of the function concept, O'Callaghan (1998) identifies and describes three essential components of understanding functions: (a) modeling, (b) interpreting, and (c) translating. Whereas modeling entails ability to represent a mathematical situation using a picture, symbol, graph or table, interpreting involves ability to draw conclusions about functions from different representations. Finally, reifying entails construction of a mental object of the idea of function from what was essentially seen as a process or procedure. In the case of functions, process or procedure refers to various operations with functions such as drawing graphs, differentiating functions, and doing analysis of functions. Accordingly, the tasks used in investigating Basotho university mathematics students' understanding of function sought to evoke responses that would reveal these various aspects of understanding the concept of function. The researcher's hypothesis was that given that most of these college mathematics specialists who took part in this study had, on average, attained a reasonable degree of proficiency in performing such operations as differentiation, integration and the proof of the continuity of function, they would be equally successful in understanding the object they have demonstrated so much success in manipulating it.

Significance of the Study

In the only study that investigated Basotho students' understanding of function, Morobe (2000) worked with a small sample of pre-service mathematics teachers (12) at the National University of Lesotho (NUL) during the 1999/2000 academic year. The results of this study suggested, amongst other things, that the teachers held a pervasive belief that every function was linear. Additionally, they struggled somewhat in dealing with the less common functions such as piece-wise functions, constant functions, and discontinuous functions. The present study was designed to extend Morobe' work by looking at a much bigger sample of 491 mathematics specialists enrolled at the NUL in the 2002/2003 academic year. This group included prospective teachers of mathematics and those who were taking mathematics as one of their two majors. Whereas Morobe used the tasks that could easily be represented either in a symbolic, graphical or tabular forms, the current study included arbitrary correspondences and implicitly defined functional situations that could not necessarily be represented in the form of a table, symbol, or graph. More specifically, the tasks used in this study included the following representations of function (a) symbolic forms of functions, (b) graphical representations of functions, (c) arbitrary correspondences, and (d) a functional situation that was described implicitly. It is hoped that the results of this study should constitute a basis for thinking about possible intervention strategies designed to improve students' understanding of function at tertiary institutions. Accordingly, research that builds on the current study might include the design of teaching experiments that are aimed at documenting students' development of the function concept in instructional settings. These ideas, when documented, can constitute a basis for developing instructional materials and activities that support or nurture the development of students' development of a richer understanding of function.

METHODOLOGY

Sample

Mathematics students enrolled at the National University of Lesotho during the 2003/2004 academic year constituted the population of the present study. Four hundred and ninety-one (491) of these students responded to a 10-item questionnaire that challenged them to define function, give an example of a function and to distinguish between functional and non-functional situations presented different representations and contexts. Table 1 show the number of students who participated in this study. This sample included some 93 social sciences students who took a second year mathematics course as a service course (M205 group). Drawn from years one through four of the degree program, the students responded to the questionnaire during regular classroom time. All students who participated in this study had undergone some formal training on the formal definition, recognition, and interpretation of functions.

Category of Students	Number of Registered Students	Number & Percentage of Students Responding to Questionnaire Number [%]
1st Year (Math)	267	250 [94%]
2nd Year (Math)	119	105 [88%]
2nd Year Soc. Sciences (Math)	101	93 [92%]
3rd Year (Math)	26	23 [88%]
4th Year (Math)	26	20 [77%]

Table 1. Number of College Mathematics Specialists who Took Part in the Survey

Instrumentation

The instrument used in this paper was designed in such a way that it would evoke responses that would reveal participants' concept image of function. The idea was to access their concept image by asking them to (a) define function, (b) provide an example of function, (c) identify functional and non-functional situations presented in the form of graph, table, or symbols, and (d) recognize a function presented in an implicit form. Adapted from Clement (2001), some of the tasks in the questionnaire required students to respond to 10 items. The first 5 of these covered the demographic characteristics of the participants. The sixth item required students to define the mathematical concept of function, and to provide an example of a function. The seventh item required students to recognize and identify functions presented in a graphical form. The eighth item asked the students to identify functions presented in a symbolic form. The ninth item challenged the students to decide whether an arbitrary correspondence presented in a tabular form (Figure 1) was a function. The last item (Figure 2) sought to determine whether the students could recognize a functional situation that was defined implicitly, and embedded in a context that was neither a graph, table, or symbols. In each case the students were given enough space to justify their responses in writing.

If we let x = club member's name and y = amount owed, is y a function of x?

Name	**Owed**	**Name**	**Owed**
Sue	$17	Iris	6
John	6	Eve	12
Sam	27	Henry	14
Ellen	0	Louis	6

Figure 1. The task showing an arbitrary correspondence.

From "What do students really know about functions? By L. Clement (2001), Mathematics Teacher, 94, 9, p. 746. Copyright by L. Clement, Reprinted with permission.

A caterpillar is crawling around on a piece of paper as shown below.

a) If we wished to determine the creatures' location on the paper with respect to time, would this location be a function of time? Why or why not?
b) Can time be described as a function of its location? Explain.

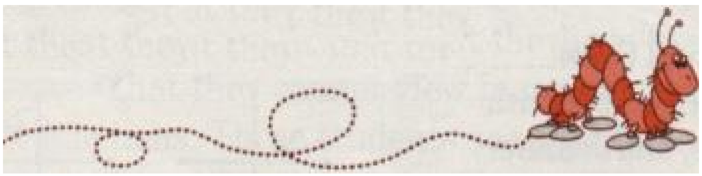

Figure 2. The task showing a functional situation defined implicitly.

From "What do students really know about functions?" By L. Clement (2001), Mathematics Teacher, 94, 9, p. 746. Copyright By L. Clement. Reprinted with permission

Procedure

The students responded to the questionnaire during regular instruction time. Prior to asking the students to respond to the questionnaire, the researcher explained that the purpose of the exercise was to study their understanding of the idea of function. Furthermore, the students were made aware that the questionnaire had nothing to do with regular testing. Finally, the researcher made sure that the students understood what each task required them to do by going through each item in the questionnaire. Completed questionnaires were collected immediately after the students had completed them. In other words, the students were not allowed to take the questionnaire home.

Data Analysis

On the basis of the researchers' own mathematical understanding of function, and on the research questions the researchers sought to pursue, students' thinking was analyzed according to five general themes: (a) definition and examples of function, (b) ability to recognize functions expressed in symbolic form, (c) ability to recognize functions presented in a graphical form, (d) ability to identify a function expressed in a tabular form but without an explicit rule linking elements of the domain and those of the range, and (e) facility at seeing and dealing with functions presented in an implicit form. Finally, a double-coding procedure (Miles & Huberman, 1994) was used to identify and categorize students' responses to each item. The researcher and another person trained to do the job independently read and coded 100 randomly sampled responses to each item. Agreement was reached on 95% of the selected cases. Disagreements were discussed until consensus was reached.

RESULTS

Students' Definitions of Function

The overall picture was that the majority of students were unable to provide a correct definition of function. Table 2 summarizes students' definitions of functions. Students from various levels of education seemed to differ in terms of the way they chose to define function. Whereas the majority of first year students [137 (55%)] defined function as a relationship that has only one image in the co-domain (range), their second year counterparts [58 (55%)] defined a function as a relationship in which the first component of the ordered pair is not repeated. The difference between the two definitions is that the latter uses ordered pairs. However, they both stress the fact that every element of the domain has exactly one image (univalence property of function). In other words, one-to-one and many-to-one relations are functional, but one-to-many relations are not functional. The majority of students in the social sciences category (those taking M205) [63 (68%)] provided a definition that seemed to emphasize the dependency property of function, with scant regard for the need for a functional situation not to have one-to-many correspondences. More specifically, they defined a function as a rule that shows how one variable depends on the other. Finally, students in the third and forth years of study tended to defined a function as a relation in which there is only one image in the co-domain in the same way as their first year counterparts.

The correct formal definition of function based on the idea of set of ordered pairs did emerge only on less than five instances. For example, Tefo in the second year of study defined a function as a "the cross product of two sets such that the first component in the ordered pair is not repeated". Some definitions stressed the fact that in a functional situation, one can have one-to-one and many-to-one situations, but not one-to-many situations. Others clearly reflected the many misconceptions that the students held with regard to function. For instance, Mpho in her forth year of study argued that a function was a "mathematical equation that has a domain and range whereby the domain is mapped to the range on a 1-1 bases. Firstly, Mpho's claim that a function is an equation underscores a possible confusion between the idea of a function as a very large abstract object and an equation a one way of modeling or representing only a limited number of functions. Secondly, her claim that the domain is mapped onto the range on a 1-1 basis mirrors a possible confusion between the univalence property of a function and the one-to-one property of some functions, with scant regard for the fact others are in fact onto. On several occasions, respondents described a function as a relation in which an input is turned into an output, showing lack of understanding of the idea of function as a special type of a relation in which each input (if we use their language) corresponds to exactly one output. It is interesting to note that less than 50% of third and forth year students dared to define a function. This suggests that their confidence with the idea of function was so low that they chose not to commit themselves.

Students' Definitions of Function	1st Year N=267	2nd Year N=119	S0c. Sciences 2nd Year N=101	3rd Year N=26	4th Year N=26	Total N=491
A function has only one image in the co-domain	137[55]	21[20]	2[2]	6[26]	6[30]	172[35]
A function shows how one variable depends on the other	0[0]	6[2]	63[68]	5[22]	5[25]	79[17]
First entry of ordered pair does not correspond to more than one second entry	0[0]	58[55]	0[0]	0[0]	0[0]	58[12]
A function is relation between variables x and y	29[12]	6[6]	12[13]	0[0]	0[0]	47[10]
A function has one image but an image can have more than one partner	10[4]	1[1]	0[0]	0[0]	0[0]	11[2]
In a function an input mapped on to an output	14[6]	0[0]	0[0]	3[13]	2[10]	19[4]
No definition	20[8]	11[10]	8[3]	0[0]	0[0]	39[8]
Numbers and letters to represent given information	0[0]	0[0]	4[4]	0[0]	0[0]	4[1]
One-to-one and onto mapping with domain and range	0[0]	1[1]	0[0]	3[13]	4[20]	8[1]
Subset of cross product of 2 sets such that first entry in the ordered pair is not repeated	0[0]	2[2]	2[2]	0[0]	0[0]	4[1]
Idiosyncratic definitions	36[14]	2[2]	4[4]	3[13]	3[13]	48[10]

Table 2. Definitions of Functions Given by College Mathematics Specialists [Number (%)]

[1] Similar concerns have been raised by a number of science graduates as well. Some examples are "materials are not available…no space to store materials, models and charts…" (personal notes)

[2] Time is constraint…I had to achieve all the objectives…I could not… reading process for the students is problem…discussion in some things becomes long…and planning could not be completed on time… (Immediately after lesson self-reflection Saira September 27, 2000)

Students' Examples of Function	Year 1 N= 267	Year 2 N=119	Social Sciences Year 2 N=101	Year 3 N=26	Year 4 N=26	Total N=491
Linear or quadratic functions	109[40.8]	36[30.3]	62[61.4]	10[38.5]	11[42.3]	228[46]
Arrow diagram	81[32]	6[6]	0[0]	0[0]	0[0]	87[18]
Exponential function	0[0]	0[0]	5[5]	0[0]	0[0]	0[0]
Students & ages, non can have more than one age	14[6]	3[3]	6[6]	0[0]	0[0]	23[5]
F(x) = [(1,5), (2,6), (2,7)]	15[6]	42[40]	0[0]	0[0]	0[0]	57[12]
F (x) = f (l, k)	0 [0]	0[0]	7[8]	0[0]	0[0]	7[1]
Other examples	0[0]	5[5]	0(0)	0[0]	0[0]	5[1]
No example given	42[17]	21[20]	14[15]	13[50]	11[42]	101[21]

Table 2. Definitions of Functions Given by College Mathematics Specialists [Number (%)]

Students' Examples of Function

As expected, the most salient features of students' understanding of function became more apparent when they were challenged to provide examples of function. Table 3 summarizes students' responses when challenged to provide examples of functions. The most common examples were functions that were either linear or quadratic. Others were an arrow diagram, series of ordered pairs, and polynomial functions, especially quadratic functions. This finding is not surprising given most of the examples used in the teaching and learning of algebra in the Lesotho context are either linear or quadratic. These examples suggest that the concept image of function that the students held was that or a relationship that could easily be described in terms of well-known functions such as those that were linear or polynomial. Surprisingly, a large number of third year [13 (50%)] and forth year [11(42%)] mathematics specialists could not provide an example of a function. This was despite the fact that these students had developed a sufficient facility at manipulating functions as evidenced by the fact that they had successfully completed the program for year 1 through 3 of university mathematics. In particular, they had differentiated functions, integrated functions, analyzed functions, and used functions as a basis for solving a wide spectrum of mathematical problems.

[3] Syllabus is a problem…some discussions become long and we rush to complete the syllabus. (Immediately after lesson self-reflection Saira September 27, 2000)

Students' Examples of Function	Year 1 N= 267	Year 2 N=119	Social Sciences Year 2 N=101	Year 3 N=26	Year 4 N=26	Total N=491
Linear or quadratic functions	109[40.8]	36[30.3]	62[61.4]	10[38.5]	11[42.3]	228[46]
Arrow diagram	81[32]	6[6]	0[0]	0[0]	0[0]	87[18]
Exponential function	0[0]	0[0]	5[5]	0[0]	0[0]	0[0]
Students & ages, non can have more than one age	14[6]	3[3]	6[6]	0[0]	0[0]	23[5]
F(x) = [(1,5), (2,6), (2,7)]	15[6]	42[40]	0[0]	0[0]	0[0]	57[12]
F (x) = f (l, k)	0 [0]	0[0]	7[8]	0[0]	0[0]	7[1]
Other examples	0[0]	5[5]	0(0)	0[0]	0[0]	5[1]
No example given	42[17]	21[20]	14[15]	13[50]	11[42]	101[21]

Table 3. Examples of Functions by Given by College Mathematics Specialists [Number (%)]

Recognition of Symbolic Representations of Function

The conjecture that the students were more likely to recognize functions in situations that could easily be represented using familiar symbolic representations, especially those that were linear and quadratic, was further supported by their responses to a task that challenged them to identify symbolic representations of relations that were functional. Table 4 summarizes students' choices of symbolic representations of relations that they regarded as functional. As shown on Table 4 about 471 (96%) of students who participated in this study correctly identified the linear function $y = \frac{x}{2}$ as representing a functional situation. Similarly, 461 (94%) students correctly identified the quadratic function $y = x^2 - 4$ as representing a functional situation. Additionally, with the exception of first year students, the exponential function ($y = e^x$) was correctly identified as a function by all categories of students who took part in the investigation. Apparently the majority of the students had met linear, quadratic, and exponential relations identified and discussed as models of functional situations. In contrast, the numbers dropped sharply in the case of the less common relations such as the piece-wise function $\begin{cases} 1 \text{ if } x \in \text{rationals} \\ -1 \text{ otherwise} \end{cases}$

[233(47%)] and the rational function $xy = 8$ [209 (43%)]. As expected, the number of students who claimed that $x^2 + y^2 = 25$ was a function was relatively low [191 (39%)]), suggesting that the majority of the students correctly identified this circle of center (0, 0) and radius 5 units did as a non-functional situation. Perhaps the students experienced more success at classifying this because they could easily visualize it as a circle, and they recalled that a circle would always fail the vertical line test for a function. In contrast, the rational function (c) and the piece-wise functions (f) were probably more difficult to visualize.

Relations	Year 1 N =267	Year 2 N = 119	Social Sciences Year 2 N = 101	Year 3 N = 26	Year 4 N = 26	Total N=491
(a) $y = x^2 - 4$	207[78]	109[92]	98[97]	24[92]	23[88]	461[94]
(b) $y = \frac{x}{2}$	211[79]	110[92]	98[97]	26[100]	26[100]	471[96]
(c) $xy = 8$	46[17]	78[66]	43[43]	18[69]	24[92]	209[43]
(d) $x^2 + y^2 = 25$	95[36]	26[22]	45[45]	11[42]	14[54]	191[39]
(e) $y = e^x$	146[55]	98[82]	99[98]	24[92]	25[96]	392[80]
(f) $\begin{cases} 1 \text{ if } x \in \text{rationals} \\ -1 \text{ otherwise} \end{cases}$	76[28]	74[62]	55[54]	10[38]	18[69]	233[47]

Table 4. Symbolic Relations Identified by College Mathematics Students as Functions [Number (%)]

Table 4 further shows that the piece-wise function (f) seemed to have caused greater difficulties to students in the third year compared to those in the fourth year. It was also interesting to note that second year students in the social sciences experienced more success in identifying the exponential relation as a function compared to their counterparts in the pure sciences. Perhaps this results from the fact that the exponential function is often used in a wide spectrum of applications in the social sciences, and accordingly it is one of the few functional representations that the students had met several times.

Recognition of Graphical Representations of Functions

Here the researcher's conjecture was that the students were more likely to experience more success at identifying functions presented in a graphical form compared to those presented in the symbolic form given that graphical representations landed themselves more readily to analysis using such learning tools as the vertical line test for a function. Table 5 summarizes students' responses when challenged to identify functions from a group of relations presented in a graphical form. Indeed, the majority of students (471[96%]) across the five groups were able to see that a graph that represented a relation of the form $y=ax^2$ represented a functional situation. As expected, a large number of participants (430[88%]) correctly identified a semi-circle that had center (0, 0) and covered the first and second quadrants (e) as representing a functional relationship. Contrary to expectations, however, the number of students who correctly classified a constant function ($y=b$) was generally low, especially amongst students in the social sciences. Interestingly, first year students did better in this exercise compared to every category of the students except those in the third year. Furthermore, graphs of the singleton point (c) and the step function (g) seemed to cause a lot of difficulties across the categories of the students who participated in this investigation. Whereas first year students outperformed every category of participants in classifying a singleton point as function, only third year students did better than them in classifying the step function as representing a functional situation. In fact only 251 (51%) of all students correctly identified this as a function. As for the step function (g), only first year students (201[75%]) and fourth year students (21[81%]) seemed to experience considerable success at recognizing this as representing a functional relationship. The foregoing were made in spite of the fact that the vertical line test could easily have been used as basis for reaching the correct conclusion that both the singleton point and the step function represented functional relationships.

Graphs of Relations	Year 1 N =267	Year 2 N= 119	Social Sciences Year 2 N = 101	Year 3 N = 26	Year 4 N = 26	Total N=491
(a) Parabola of the form $y=ax^2$	220(82)	106(89)	97(96)	24(92)	24(92)	471[96]
(b) Relation of the type $x=ay^2$	62(23)	60(50)	73(72)	11(42)	14(54)	220[45]
(c) Singleton point	165(62)	44(40)	23(23)	10(38)	9(35)	251[51]
(d) Function of the form $y=b$, where is b is a constant	194(73)	75(63)	35(35)	11(42)	21(81)	336[68]
(e) Semi-circle with center (0,0), covering 1st and 2nd quadrants	208(78)	88(74)	90(89)	23(88)	21(81)	430[88]
(f) Semi-circle with center (0,0), covering the 1st and 4th quadrants	50(19)	41(34)	69(68)	12(46)	15(58)	187[38]
(g) Step function	201(75)	49(41)	36(36)	11(42)	21(81)	318[65]

Table 5. Graphs of Relations Identified by College Mathematics Students as Functions [Number (%)]

[5] According to the textbook a radial segment is a line which joins the centre to circumference and radius is the distance between the centre and circumference.

As for identifying non-functional situations, results suggest that only 220 (45%) incorrectly identified a relation of the form $x=ay^2$ as a function. In other words 55% of the students correctly figured out that this did not represent a function. In this case first year students apparently experienced more success at classifying this relation as evidenced by the low the number of those who claimed this was a function. Similarly, only 187 students incorrectly identified a semi-circle covering the first and 4th quadrants as representing a function, which means that 62% correctly noted that this semi-circle did not represent a function. Once again more first year students correctly identified this as not representing a functional situation compared to students in the second, third and fourth years of study. In this case the researcher's conjecture that the students would experience greater success at classifying relations represented in a graphical form compared to those represented in a symbolic form was not supported. On the contrary, the students seemed to classify graphical representations of relations rather differently, showing greater facility with those they had apparently met before.

Recognition of an Arbitrary Correspondence as a Functional Situation

In order to explore students' ability to decide whether a functional relationship presented as an arbitrary correspondence was indeed a function, the students were confronted with an item showing the status of club members' dues (Clements, 2001) (see Figure 1). They were then told that x equals club member's name and y equals amount owed. They were then challenged to decide whether y was a function of x, and to justify their decision. This situation was an arbitrary correspondence in the sense that there was no specific rule that seemed to associate a club member' name to the amount owed as in the case of other forms of functions. In addition, this relationship could neither be presented in a symbolic or graphical form in the same way that one could represent linear, polynomial or exponential function. Although the majority of participants did not provide responses, the item shown in Figure 1 was able to generate a range of responses that revealed some interesting aspects of students' thinking about the idea of function. Table 6 summarizes students' responses to this item. It must be noted that compared to item 7 (graphical representations of functions) and 8 (symbolic representations of functions), this item was a bit unusual in the sense that the students had not met similar problems in their day-to-day mathematics lessons. Furthermore, it caused a lot of conceptual challenges as evidenced by the low number of students who were able to respond to it.

Students' Analyses of an Arbitrary Correspondence	Year 1 N =267	Year II N = 119	Social Sciences Students N =101	Year 3 N = 26	Year 4 N = 26	Total N= 491
Yes! Amount is owed to one member	118(47)	22(21)	36(39)	7(30)	0(0)	183[37]
No! Y does not depend on x	0(0)	5(5)	28(30)	3(13)	2(10)	38[8]
Yes! Amount reflects character of club member	0(0)	0(0)	6(6)	0(0)	0(0)	6 [1]
Yes! No explanation	31(12)	30(29)	0(0)	2(9)	4(20)	67[14]
No! No explanation	7(3)	22(21)	0(0)	2(9)	11(55)	42[9]
No! Different names have same amount	32(13)	11(11)	0(0)	6(26)	0(0)	49[10]
Yes! After drawing an arrow diagram	9(4)	0(0)	0(0)	0(0)	0(0)	9[2]
Other Responses	6(2)	2(0)	14(15)	0(0)	0(0)	22[4]
No Response	42(17)	17(16)	9(10)	3(13)	3(15)	74[15]

Table 6. College Mathematics Students' Analyses of an Arbitrary Correspondence [Number (%)]

The most common incorrect response across the four groups (183[37%]) was that the task shown in (Figure 1) represented a function because, as Thabang argued, "The amount owed was owed to one member". This response was indeed incorrect for, as shown on Figure 1, John and Iris actually owe the same amount. Furthermore, 49(10%) students argued that item 9 did not represent a function because 2 members owed the same amount. As Molete explained it, "This is not a function because Iris, Louis, and John owe the same amount and this means we have more than one image." Other students justified similar responses by drawing an arrow diagram that showed amount owed (y) as constituting the domain (corresponds to objects) and club member's names (x) as co-domain (corresponds to image). It should be noted that, in this case, an arrow diagram was used as basis for reaching an incorrect decision. The foregoing perceptions could have resulted from a misunderstanding of the phrase "y is a function of x". Whereas a correct interpretation of "y is a function of x" is that y depends on x, an incorrect interpretation that surfaced in this case was that "y is a function of x" means x depends on y.

Furthermore, students' responses to this item also suggest that, because their concept image of function was that of a relation that could be expressed using either a formula or graph, they had difficulty in recognizing and accepting a functional relationship that was not be expressed in any of the usual representations. Common incorrect responses included expressing discomfort with the fact that there seemed to be no explicit relationship between a club member's name and the amount owed. For example, Matseliso argued a similar point thus: "No, y is not a function of x. There is no way the member's name and amount owed are related". Clearly, Matseliso is perturbed by the fact that there is no explicit relationship between a member's name

[6] Based on concepts such as learning with reasoning, encouraging students' participation in activity and thinking and organising the classroom for cooperative learning

and the amount owed. Other students seemed to express a similar sentiment, but were more forthright about what they objected to compared to Matseliso. For instance, Thabo said Figure 1 did not represent a functional relationship for as he explained it, "Club member's names are not represented by digits". Consistent with this type of thinking, Lineo said: "Y is not a function of x because the member's name does not depend on the amount owed. We cannot construct an equation that relates y to x". Thus these students were not inclined to accept an arbitrary correspondence as a function. More specifically, they seemed to be looking a numerical relationship that could easily be represented symbolically. Apparently, their experiences with functions had excluded arbitrary correspondences that could be functional or non-functional. More importantly, they were not aware that symbols and graphs are merely models or representations of abstract objects called functions, and that some of these objects can neither be represented graphically nor symbolically.

As in the case of graphical representations of functions, traces of correct classification of the relation shown in Figure 1 as functional seemed to emerge from the first year category of participants. Correct responses included mentioning the fact that one member owed one amount. As shown in Table 6, some 9 (4%) first year students drew an arrow diagram, the first column of which showed names of club members (x) and the second column of which depicted the amounts owed (y) before reaching the valid conclusion that Figure 1 represented a functional relationship. Apparently, the arrow diagram did enable the students to recognize that whereas the relation consisted of one-to-one and many-to-one correspondences, one-to-many correspondences did not exist. In other words, they did realize that the situation shown in Figure 1 did satisfy the univalence property of function. Thus the arrow diagram was correctly used in this case as a tool of analysis that enabled the students to decide whether the arbitrary correspondence described in Figure 1 indeed represented a functional relationship. It should be noted that the students could, for the task shown in Figure 1, easily landed itself to analysis using an arrow diagram. The researcher further sought to find out how the students would deal with a functional situation that could neither be represented using a symbol, graph or arrow diagram.

Recognition of a Function Defined Implicitly

In the last item adapted from Clements (2001), the students were shown the picture of a crawling caterpillar that first moved forward (not in a straight line) for a few minutes and then turned around before continuing for a few minutes (see Figure 2). Then the creature turned around again before continuing. Thus the path of the caterpillar consisted of several loops. The students were asked to say whether location would be a function of time if one wished to determine the caterpillar's location on paper at a particular time. Table 7 summarizes students' responses to item 10.

Students' Response	Year 1 N=267	Year 2 N=119	Social science Year 2 N=101	Year 3 N=26	Year 4 N=26	Total N=491
(a) Yes! Location would be a function of time because location depends on time, and time keeps on changing.	49(20)	41(39)	71(76)	12(52)	6(30)	179[36]
(a) No! Location is not a function of time because the creature crosses one place more than once.	106(42)	30(29)	5(5)	8(35)	5(25)	154[31]
(a) No! Location is not a function of time because the caterpillar keeps on changing speed.	6(2)	0(0)	4(4)	0(0)	1(5)	11[2]
(a) No! Location is not a function of time because vertical line test fails.	17(2)	3(3)	0(0)	0(0)	1(5)	21[4]
(a) Other responses	13(5)	13(12)	12(13)	5(22)	7(35)	50[10]
(a) No response given	35(14)	19(18)	4(4)	0(0)	0(0)	58[12]
(b) Yes! Time can be a function of location (no explanation)	23(9)	20(19)	39(42)	0(0)	5(25)	87[18]
(b) No! Time cannot be a function of location because one location can have different times	31(12)	20(19)	22(24)	12(52)	6(30)	91[19]

Table 7. College Mathematics Responses to the Item on the Caterpillar Moving in Loops [Number (%)]

The task on the crawling caterpillar confronted the students with a lot of difficulties as evidenced by the low number of those who provided responses. The most common incorrect response was that location would not be a function of time because the creature seemed to have been at the same place at the same time. Thabiso echoed a similar sentiment in arguing as follows: "This is not a function because as we look at our time, the creature crosses twice at a certain point of time. This means that a certain distance has different time intervals which do not agree with the function rule of having only one image for each object". Once again the confusion here seems to reside in students' lack of understanding of the question:" Would location be a function of time?" More specifically, they were apparently unable to identify the dependent and the independent variable. In the foregoing question location is the dependent variable and time is the independent variable. Although different times can correspond to one location, each time will have exactly one location. Therefore location is indeed a function of time since the univalence of property of function is satisfied. Apparently those who reasoned like Thabiso took location as the independent variable and time as the dependent variable.

Another common misconception was the tendency to regard the path of a crawling caterpillar as a model or graph of the relationship between location and time. Consequently, some students erroneously applied the vertical line test to reach the incorrect conclusion that location was not a function of time. For example Tumo argued that location was not a function of time for as he explained it, "The vertical line cuts the graph twice at the same points". This response not only reflects a mechanical understanding of the use of the vertical line test as a tool for testing whether a relationship was functional but it also mirrors failure to identify related variables and to correctly interpret their behavior. As in the case of an arbitrary correspondence (Figure 1), these responses also showed lack of understanding of the phrase "is a function of." For these students, location was mapped onto time, and consistent with this way of looking at things, the same location would be mapped onto different times, violating the univalence aspect of the definition of function.

The most common correct response was that location would indeed be a function of time because time kept on changing even though, in some occasions, the distance covered did not change. As Mahlape explained it, "location would be a function of time because the caterpillar can be at any location at different times. Meaning that for different locations there can never be the same time." This explanation suggests that Mahlape has not only correctly identified related variables but also understand their behavior. Interestingly, students in the social sciences seemed to experience more success at answering this question correctly [71 (76%)], with first year students showing the least success. With regard to the second part of the same task where the students were challenged to say whether time would be a function of location, only 91 (19%) of all students correctly concluded that time would not be a function of location because one location would be mapped to more than one reading of time. As in the case of the first part of the task, a greater proportion of third year students [12(52%)] reached a correct conclusion, and the smallest proportion of first year students [31 (12%] provided similar responses.

CONCLUDING REMARKS

The purpose of this exploratory study was to look at Basotho university mathematics students' understanding of the notion of function. Although the absence of interviews with a sub-sample of those who responded to the questionnaire calls for caution in drawing conclusions, students' work as they responded to the questionnaire and justified their responses in writing has revealed some interesting aspects of their thinking with regard to the idea of function. In particular, the results suggest that the majority of the students generally had enormous difficulty in providing a correct definition of the notion of function. The definitions were often incomplete, with the students mentioning only one aspect of the definition of function. Whereas mathematics majors tended to stress the univalence aspect of the definition of function, their social sciences counterparts emphasized the correspondence or dependence aspect of the definition of function with scant regard for the univalence property of function. The fact that even third and fourth year mathematics specialists could not provide a correct definition of function when challenged to do so, suggests that interactions with function as been more operational than structural (Tall, 1996). That is, they have, amongst other things, successfully evaluated functions, differentiated functions, integrated functions, and analyzed the continuity of functions without adequately understanding the nature of the object they have been handling. There is a need therefore to restructure the university mathematics curriculum so that it provides a balanced combination of the operational and structural aspects of the idea of function.

The examples of functions that the students provided seemed to illuminate their concept image of function. In line with past research in this knowledge domain (e.g. Markovits et.al. 1988; Vinner, 1992), students' concept image of function was limited to a few prototypical situations, especially linear and polynomial functions. It was found that the majority of the students provided either linear or quadratic functions as examples of function. Given that most of the elementary algebra introduced in the secondary and high schools is essentially the study of linear and polynomial functions, students' examples of functions reflects the depth and breadth of the algebra they have studied from the high school through to the university. At the university level, it is possible that professors of mathematics genuinely choose linear and polynomials functions as easier examples of functions in order to help the students understand this apparently illusive concept. Consequently, the students end up internalizing linear and polynomial functions as prototypes of functions. In other words, when challenged to give an example of a function, concept images that is immediately evoked are that of a linear or quadratic functions. Apparently, this process continues throughout the fours years of learning mathematics even though college mathematics should constitute a context for extending and deepening students' understanding of the idea of function. To remedy this situation, those involved in the teaching and learning of functions at the school and tertiary levels might use examples and non-examples of function that deepen and expand rather than limit students' understanding of functions. This can be attained if the activities that high school and university mathematics students experience do include exposure to linear, polynomial, exponential, rational, trigonometric, and other types of functional situations in a technologically-rich learning environment. It is a well-known fact technological devices such as graphing calculators can enable students to model and visualize complicated functions that are impossible to sketch by free hand.

Consistent with their choice of examples of function functions, students' ability to identify functional and non-functional situations from a group of relations presented in symbolic and graphical forms seemed to be constrained by the breadth and depth of their past experiences with functions. In other words, their classification of symbolic and graphical representations of functional and non- functional situations was limited to some prototypes of functions and non-examples of functions. For example, they experienced little difficulty in correctly identifying linear and quadratic relations as functions. Consistent with their past learning experiences, students in the social sciences were the most successful in recognizing that the exponential function was indeed a function. Additionally, many showed not much difficulty in seeing the equation of circle with the origin as the center, and radius 5 units did not represent a functional situation. Surprisingly, many had problems recognizing that the graphs of a singleton point and that of step function represented functional situations even though they could have easily used the vertical line test. It is possible that linear and quadratic functions are often used as examples of functions, and a circle is usually used as a counter-example of a model of a functional situation. In contrast, the students experienced great difficulties in identifying the piece-wise function and the rational relations as functions. Once again mathematics teachers and educators might do well to ensure that examples and non-examples of functional situations extend beyond the familiar linear relations, quadratic relations and other models of relations. It is clear that with the use of traditional pencil and paper, it may not be possible to expose students to as many examples and non-examples of functions as is necessary. In most institutions of higher learning, students do not only learn how to sketch and draw functions, they also employ electronic devices (e.g. graphing calculators) to draw and to learn about the behavior of some functions for which it would be impossible to draw or sketch using paper and pencil alone. Morobe (2000) recorded some positive changes after exposing a small group of prospective teachers of mathematics to a series of instructional sessions in which the graphing calculator was an essential component. Greater changes in students' conceptual understanding of functions can be attained if students are exposed to at least three types of learning experiences: (a) lecture, (b) pencil-and-paper tutorial, and (c) tutorial using either a computer or graphing calculator as a learning resource.

When challenged to decide whether a table that depicted an arbitrary (Figure 1) correspondence was a function, the majority of students had great difficulty in providing responses. Similarly, a very small number of the students responded to the item on the crawling caterpillar (Figure 2). Apparently, some were perturbed by the fact that there seemed to be no explicit rule or equation that connected the variables in the table. Others openly expressed their frustration with the fact one the variables (names of club members) was not represented by digits. These responses underscore a serious gap in students' understanding of function, namely, that even arbitrary correspondences can be functional or non-functional situations. Furthermore, many had apparently not come across a functional situation that was not defined using conventional forms of representations as described in task on the crawling caterpillar. More seriously, there exists confusion between the idea of a function and an equation. Whereas a function is an abstract object, an equation is a model or symbolic that can be used to represent some but not all functional situations. Similarly, a table and a graph constitute alternative ways of representing or modeling functional and non-functional situations. Thus it is essential mathematics teachers and educators to design learning situations that will enable students to conceptually draw a distinction between a mathematical concept of function and its symbolic, graphical, and tabular representations. Moreover, it is important to stress the fact that these representations may not be used to show all existing functions. It is essential that instruction on functions exposes students to a wide spectrum of functional and non-functional situations, including arbitrary correspondences (Figure 1) and those that are defined implicitly (Figure2).

There was also some confusion with the use of the phrase "is a function of". In particular, some students argued that the arbitrary correspondence shown in Figure 1 was not a functional situation for as they argued, John and Iris owed the same amount (6). For this category of students, the confusion seemed to reside in meaning of the phrase "y is a function of x".

Apparently they regarded this to mean that "x depends on y" rather than "y depends on x". This misconception resurfaced again when students were challenged to respond to the task on the crawling caterpillar. Some students argued that location would not be a function of time for as they explained it, "the caterpillar would be at the same location at different times". Clearly, these students had misinterpreted the phrase, "location is a function of time" to mean time depends on location rather than location depends on time. Thus students' access to the meaning simple expressions such as "y is function x" should not be take granted. On the contrary, mathematics educators and teachers should expend more time to ensure that these are well understood. Interestingly, some students were able to correctly decide that the arbitrary correspondence shown in Figure 1 was a functional situation by drawing an arrow diagram that clearly suggested that the table satisfied the univalence requirement for a function. In this case an arrow diagram was used as a representational tool that made a functional relationship more apparent. Once again effort should be made to draw a distraction between an abstract object of function and an arrow diagram as a model or a representational tool, and that some functions may not be represented in the form of an arrow diagram.

As this was an explanatory study, further research in this area might be aimed at documenting, in greater detail, how students acquire increasingly complex ideas of function in an instructional setting. Such teaching experiments necessarily have to be preceded by collection of baseline information by way of a questionnaire coupled with clinical interviews that cover a wider spectrum of constructs, including the idea of a function as an abstract entity that can be represented in several ways, arbitrary correspondences, equations, arrow diagrams, tables, graphs and those defined implicitly. When available, the data generated from these teaching experiments should not only contribute to theory-building on the development of functional concepts but it should also serve as a basis for developing appropriate instructional materials, including books and manuals. More importantly, it should enable curriculum developers to review the school mathematics curriculum in such a way that the idea of function becomes a unifying theme. Additionally, the information generated from the teaching experiment should produce important ideas about how to best design instructional situations that support rather than limit students' understanding of function.

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A NEW GRAPHICAL LOGO DESIGN: LOGOTURK

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Soner Durmus

ABSTRACT. The development of abstract mathematical thinking is an essential part of mathematics and the geometry is regarded as a suitable domain to serve this purpose. As different technologies such as computers and graphing calculators are widely being used, curriculum developers on geometry should take these technologies into consideration. Several Logo-based computer environments have been designed to develop conceptual understanding and abstract thinking in geometry. A new graphical logo environment, LogoTurk, have been designed to eliminate some deficiencies in these environments and to provide a graphical environment in which students could explore geometric concepts and relations in different ways. The purpose of this paper is i) to present the pedagogical needs to develop a new graphical logo design, ii) to introduce the graphical features of LogoTurk meeting these needs, iii) to evaluate this new design.

KEYWORDS. Logo, LogoTurk, Graphical design.

INTRODUCTION

Geometry is an abstract branch of mathematics that helps students reason and understand the axiomatic structure of mathematics. Because of the nature of concepts and relations of geometry, it is an abstract subject for most of the primary school students (NCTM, 2000). It is concerned with finding the properties and the measurements of certain geometric objects. Geometric properties are those properties of the objects that remain invariant under certain transformations when the sizes and measurements of the objects change. Carpenter et al. (1980) and Flanders (1987) claim that current geometry curricula focus on lists of definitions and properties of shapes, and learning to write the proper symbolism for simple geometric concepts. Having a relational understanding means that one should be aware of knowing why and how to do certain operations. Using relational understanding for teaching geometry emphasizes concepts, such as angles, sides, triangles etc. and analyzes the spatial relationships, such as angle measure, length, area, congruency, and parallelism. This approach helps students' to develop their conceptual understanding and improve their usage of conceptual knowledge during problem solving process.

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There is a commonly accepted theory, which is based on studies of Pierre and Dina van Hiele, to explain and help us on understanding of development of geometrical thinking of students. Van Hiele's theory proposes that students move through different levels of geometrical thinking (Clements & Battista 1992). Curriculum developers and teachers should consider these levels by enriching learning environment to help students progress from one level to the next level since these levels are progressive (Burger & Shaughnessy, 1986). It is claimed that current primary geometry curricula neglects and do not promote opportunities for students to use their basic intuitions and simple concepts to progress to higher levels of geometric thought. This problem becomes more apparent in high school where students are required to employ their deductive reasoning (Hoffer 1981; Shaughnessy & Burger 1985). Deficiencies on conceptual and procedural understanding of students cause problems for the later study of important ideas such as vectors, coordinates, transformations, and trigonometry (Fey et al. 1984).

LOGO GEOMETRIES

Students at early van Hiele levels need to experience with concrete materials. Action is a very important component in the development of geometrical thinking (Piaget and Inhelder, 1967). Physical actions with concrete materials are crucial for students to internalize geometric notions. Technology enables students to visualize geometric concepts and relations in a more concrete sense. For instance, geometry rods, geobord, isometric papers, symmetry mirrors etc. are some examples of technologies that might help students construct geometric ideas. Geometry standards put emphasize on focusing on the development of careful reasoning and proof using definitions and established facts (NCTM, 2000).

Logo geometry environments claim to facilitate the developmental process of geometrical thinking. For example, students might transfer their actions to logo environment on the computer via giving directions to the turtle on the screen. Hence, through monitoring actions of the turtle, they might internalize their own physical actions as to develop geometrical interpretations of actions at hand.

Logo environments are designed to achieve three major goals (Clement & McMillen, 2001, pp.14-15): i) achieving higher levels of geometric thinking, ii) helping students learn major geometric concepts and skills, and iii) developing power and beliefs in mathematical problem solving and reasoning. Developers of Logo Geometries have assumed that curriculum has three strands: Paths, shapes, and motions. Relational understanding can be based on these three strands. The rationale behind developing Logo environments is to facilitate constructivist philosophy of learning which emphasize active involvements of students during teaching-learning process. The details of this issues is discussed by Karakirik and Soner (2005).

FIRST PHASE OF LOGOTURK

The development of LogoTurk environment passed through two phases. In the first phase, a logo environment that accepts classical logo commands in its traditional form in different languages were implemented (Karakirik and Durmus, 2005). For instance, Fig. 1 shows how to write a procedure producing a hexagon of lenght 60 pixels with traditional Logo commands in LogoTurk.

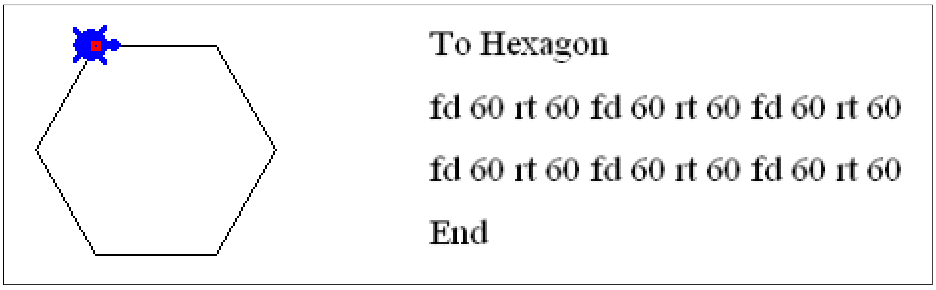


Figure 1. Drawing a hexagon in LogoTurk

One can also construct the same hexagon with the following code using a loop.

Repeat 6 [forward 60 right 60]

Similarly, Table 1 shows how to construct any regular polygon with a loop.

Equilateral Triangle	**Square**	**Regular n-gon**
To Triangle Repeat 3 [forward 50 right 120] End	To Square Repeat 4 [forward 50 right 90] End	To NGon(_n) Repeat _n [forward 50 right 360/_n] End

Table 1. Procedures of Creating Regular Polygons

LogoTurk adopts a different way of defining a procedure with the help of a procedure editor. This design also enabled testing of each procedure separately and minimized the students' loss of data. One can add, delete, rename , run and stop each procedure separately by related menu items and shortcuts in LogoTurk. In addition, it has an error detection mechanism which enables both detection and removal of small typographical errors. Karakirik and Durmus (2005) provide the details of the implementation of the first phase. LogoTurk enables students and teachers to pose and solve their own problems. One can construct, for instance, creative figures with the help of iterations (See Appendix A) or a desired specific shape such a house (See Appendix B). It also allows students to save configurations and their sequences of actions.

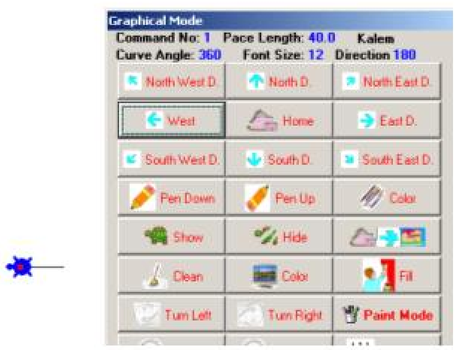
The modifications made in the first phase did not remove some deficiencies encountered in the classical Logo environment. We have translated the classical Logo commands to Turkish in order to remove the language barrier since Logo strictly relies on syntax to carry out simple commands. Although we were able to integrate all classical Logo commands in our environment, a need arose to develop a totally new approach to eliminate the difficulties with syntax and the traditional implementation of Logo itself. Hence, we developed a new graphical interface of LogoTurk in the second phase.

PEDAGOGICAL CONCERNS ABOUT LOGOTURK

This section provides the pedagogical needs to develop new graphical design for classical Logo Environments. We will outline the pedagogical issues by outlining the new features of the graphical version of the LogoTurk.

There is always a concern that integrating graphical elements to any software packages could reduce users' cognitive involvement with the task at hand and may distract their attention from intended objectives. Some also may regard the reducing Logo commands to graphical elements as educationally unfavorable because of the aforementioned concerns. The graphical elements of LogoTurk is designed in a way that students need to utilize their conceptual knowledge. For instance, mouse movements that enable easy modification of drawn figures by dragging certain points are disabled. Instead, students are required to use classical Logo commands to make the necessary changes.

The graphical version of LogoTurk dynamically links different representations and maintain a tight connection between pictured objects and symbols. A student can act both as a turtle moving on the screen and as a person monitoring out of the screen by using different modes giving different meanings to directions. For instance, if a student wants to move the turtle to north, he/she can use either "North D." button as a person monitoring out of the screen (See Fig. 2) or "Left" button as a turtle moving on the screen (See Fig. 3). The switch between these two modes may enable students to reflect on their actions and may change their perceptions about the relative meanings of angles and directions. Therefore, LogoTurk could be used to assess students' conceptual knowledge about the relative meanings of angles and directions.



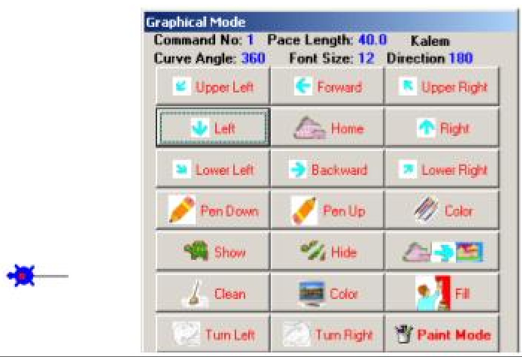


Figure 2. As a person monitoring out of the screen : Using real directions mode	**Figure 3.** As a turtle moving on the screen: Using relative directions mode

LogoTurk as a computer manipulative might provide an environment including tasks that cause students to see conflicts or gaps in their thinking. For instance, requiring students to draw a simple house with two windows, a door and a roof in aforementioned two modes could be a real eye-opener.

Although constructing a house as a person monitoring out of the screen resembles to drawing a house picture in "Paint" program, constructing a house as a turtle moving on the screen requires using one's conceptual knowledge about the relative meanings of angles and directions and seemingly much more difficult.

The biggest advantage of the graphical version of LogoTurk is eliminating students' dependency on both syntax and semantics of the classical Logo environments. One can get rid of the syntax of Logo by pressing certain buttons instead of writing a code to give a command to the turtle. Similarly, one can avoid the semantics of Logo by switching between relative and real mode of directions. Hence, LogoTurk as a mathematical tool allows students to develop increasing control of their actions. Although the classical Logo is designed for emphasizing the relative meaning of the directions requiring one to see himself/herself as a turtle moving on the screen, it might be beneficial to make switches in the real world. For instance, an architect might employ both modes to construct certain parts of his/her design.

The graphical version of LogoTurk also supports creating procedures by dynamically grouping a number of actions under a macro name. One can start a macro definition by pressing the "Start" (Macro) button and stop it by pressing the "Stop" (Button). The macro is defined relatively with respect to the mode (See Fig. 7). Students could re-use the created macro either by a name or making a selection from a list of defined macros. It is claimed that students could better appreciate the meaning of a procedure in this way as a group of repeated actions without having any difficulty with the syntax of writing a procedure. Furthermore, LogoTurk also supports writing procedures in a separate text window in case complex figures need to be constructed with the help of iterated commands.

The graphical version of LogoTurk helps to visualize the effects of the classical logo commands. Every action performed by pressing a button is recorded and translated to the classical logo commands. The history of the action were also displayed at the bottom(See Fig 7). Therefore, It is claimed that students could grasp easily the meanings of the classical commands while they construct their geometric figures with graphical elements. Some graphical elements, such as "Arc left" and "Arc Right", produce actions that could be performed by a set of classical logo commands. LogoTurk also introduced a completely new command "Sethome" to set any point on the screen as a reference point for further operations. For instance, Fig. 4 shows how to construct a directions macro showing the usual 8 directions employing the classical "home" command. However, calling this macro always produces the same figure since the reference point for home is predefined.

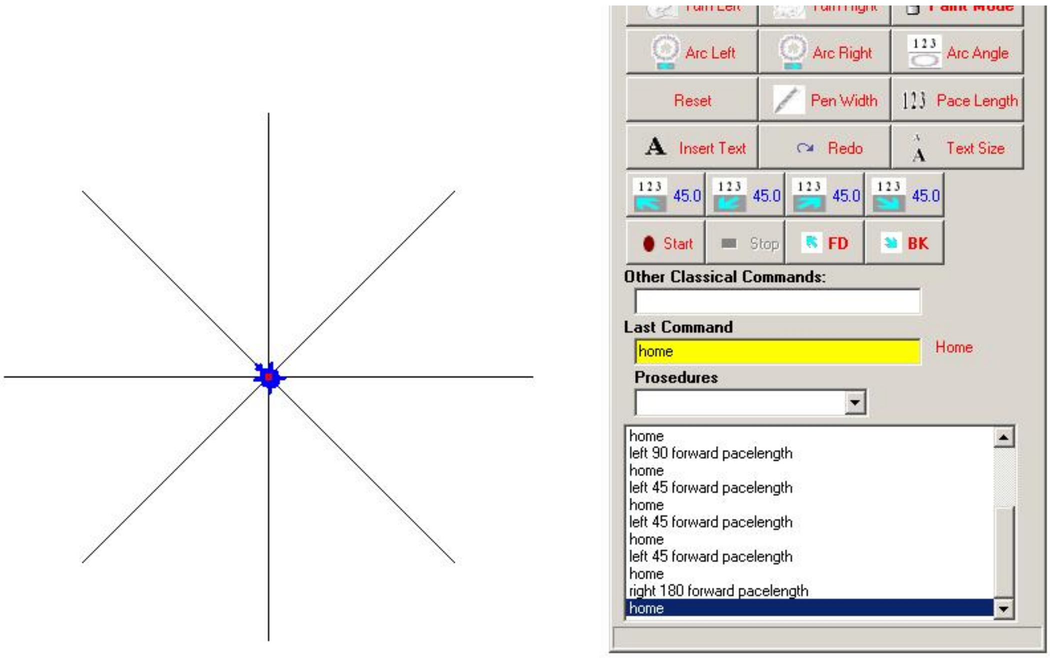


Figure 4. The macro definition of "Directions" with "Home" command in LogoTurk

However, Fig. 5 presents a complex figure produced by calling the defined "Directions" macro at different reference points (i.e. home) set by "SetHome" command. This gives flexibility to recall a figure at any part of the design.

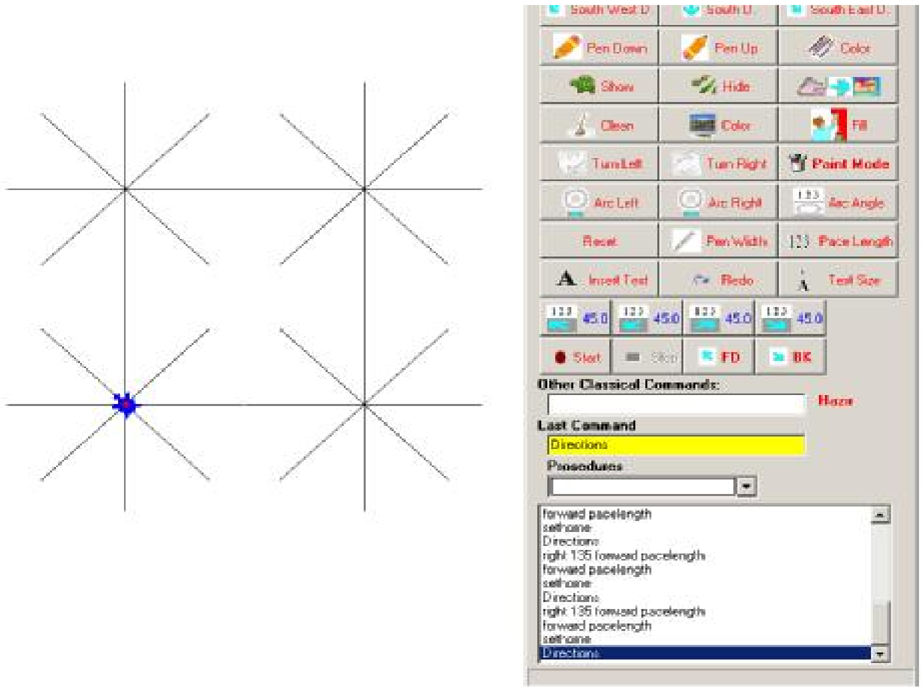


Figure 5. The usage of newly introduced "SetHome" command in LogoTurk

LogoTurk also provides a facility to undo the last action to improve user-friendliness. However, the provision of such a facility might contradict the initial Logo philosophy which aims students to find the correct action by trial and error method. Hence, the undo action is hidden in the graphical interface, could be executed by the classical Windows shortcut (Ctr-Z) and could be activated and deactivated by related menu items. The rationale for adding this feature was to encourage students to try different geometric figures without worrying about the mistakes that he/she can not recover. This also resembles the similar facilities found in "Paint" programs so that students may feel comfortable with using the system. It might help creating implicit associations between geometry and other drawing programs that some professionals such as architects and engineers use.

THE DESIGN OF GRAPHICAL VERSION OF LOGOTURK

Design is a very important part of the development of any system. The best system could be described as a transparent system that does not allow the medium used, the computers in this context, interfere with the task but enhance the user's experience without changing the nature of the task. A crucial aspect of the design of a system is the continuous and iterative nature of the design process that is carried out with the help of experimental studies. However, there are some design issues that can not easily be resolved by experimental studies. There might be several possible working versions of the same system. Hence, priorities and the specifications of the system should be determined in advance by considering the requirements and the convenience of the task at hand as far as possible.

Prior conventions and the author's own preferences might be used to make some design issues. However, employment of evaluators that are expert on the application domain is also necessary to detect some problems and to decide some issues with the system. Three to five evaluators are considered as optimal since different evaluators could find different problems (Nielsen, 1994). Guidelines for the user interface and some checklists might also be beneficial in the early stages of the development. For instance, Nielsen (1994) puts forward such a 10 items checklist, called heuristic evaluation for this purpose. It propagates a minimalistic and simplistic design based on functionality of the system and also includes items for checking consistency, flexibility, documentation, diagnosing and recovering errors, and visibility of system status and utilization of visual clues where appropriate. These considerations were taken into account during the development of LogoTurk. This section gives the details of the new design of LogoTurk.

The classical Logo commands were integrated into the design of the graphical version of LogoTurk by the provision of an area named "Other Classical Commands" to enter them manually (See Fig. 6). This might give students the flexibility to use their accustomed way of using Logo so that they may feel comfortable. Furthermore, students may choose to switch to the classical mode completely by a related menu item. Graphical elements in the form of icons were developed for most commonly used Logo commands (See Appendix C). It is possible to switch between graphical and classical mode by choosing related menu items. There is also an option to simulate turtle's actions in a quick or slow fashion. This option abolishes to enter classical "wait" command to see the effects of each individual turtle action.

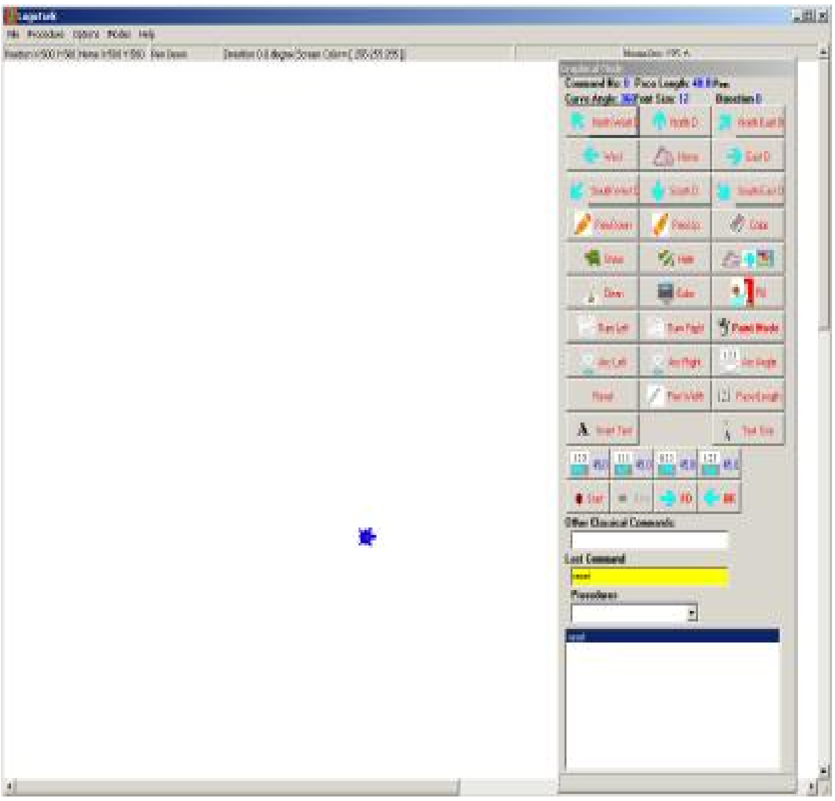


Figure 6. Graphical Version of LogoTurk

These icons, when pressed, converts users' actions into classical Logo commands and pass them to Logo engine be executed. One icon press may produce a block of Logo commands. For instance, pressing "Arc Left" icon produces the following block of Logo commands:

repeat 36 [lt 10 fd 40]

There are also some global variables to direct turtle's actions in a uniform way. For instance, the pace length variable defines the length of turtle's pace for moving any direction. Moving the turtle forward one pace results in moving the turtle forwards as the value of the pace length variable.

The history of turtle's precious actions could be seen in a combo-box at the lower part of the graphical interface. This combo-box and the "last command" section of the interface was updated after new Logo commands were produced as a result of users' key presses. There is also a command line to enter any classical Logo commands without using the graphical elements. This facility is useful especially for creating repetitive actions of turtle. For instance, the following command draws a regular hexagon:

repeat 6 [lt 60 fd 50]

Procedures are defined in classical Logo in order to reproduce a set of commands resulting in a certain figure or group of actions. Likewise, procedures are simulated as macros in LogoTurk. A number of actions can be recorded as a macro by defining a starting and ending points by pressing related icons. For example, pressing four times Left button produces a square of one pacelength. One can record it as a macro by giving it a name as a "square" and several "squares" can be constructed by recalling this macro from procedures section shown in Figure 7.

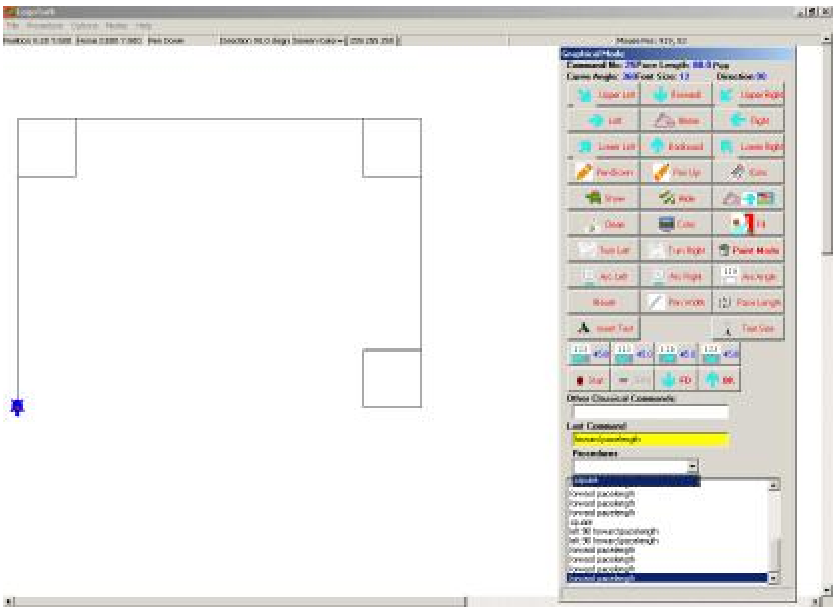


Figure 7. A macro definition of a square in LogoTurk

There are two different set of icons for 8 directions that controls the motions of the turtle. One set of icons are static denoting the known directions, namely east, north east, north, north west, west, south west, south and south east , east, north east, north, north west, west, south west, south and south east. The second icon set controls the motions of the turtle as if the user moves as a turtle itself and the directions that icons denote change with respect to the turtle's current position and direction. The icons in the first set always show the same direction while the directions of icons in the second change after every movement of the turtle. Different names are used for icons to denote the differences between two sets. While the first is set claimed to be proper for easy construction of certain shapes regardless of turtle's position such as a house, the second set is much more consistent with Logo paradigms and proper for drawing and seeing geometric shapes such as square. For instance, Figure 8 shows two different ways of constructing a square with two different icon sets. The absolute direction with "setheading" command is used in left part of Figure 7 while the relative direction with "left" command is used in the right part of the figure. There is a need to investigate the effects of these two different modes on students' conceptual understanding of geometric relations existing in the figures.

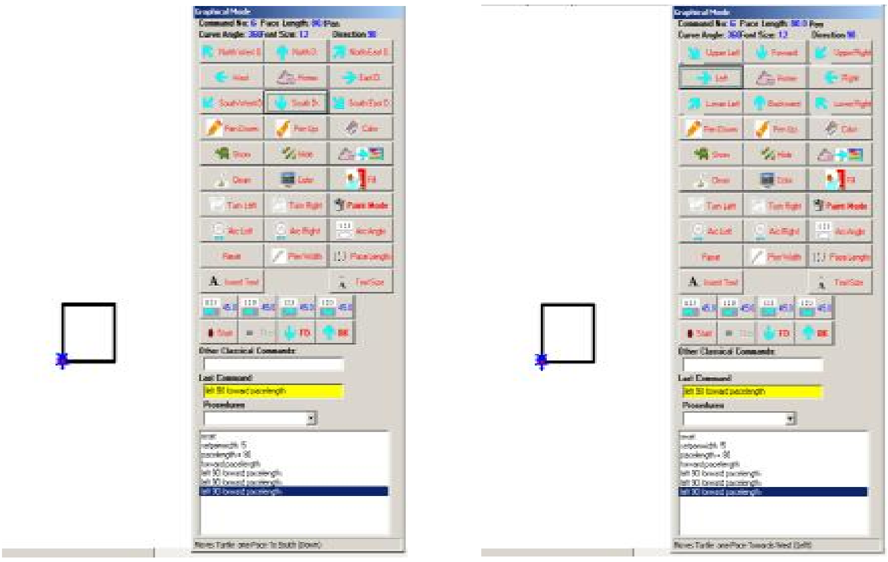


Figure 8. Drawing a square using two different set of icons in LogoTurk

AN EVALUATION OF LOGOTURK

We successfully designed a new graphical version of Logo Environment. Our design differs from other graphical designs in a way that it not only includes the all classical Logo commands with graphical elements but also introduces new ways of experiencing geometry in Logo environment.

Our new design provides an environment where a student can act both as a turtle moving on the screen and as a person monitoring out of the screen. This might help students grasp different interpretations of relative meanings of angles and directions. It is suggested that students might create geometric constructs resembling what architects and engineers make. So, geometry might be seen as a part of the real life. Our new design has the potential to enhance students' geometry experiences and enrich their geometrical thinking. So, it is claimed that designing user friendly interfaces for Logo may change students' perception of Logo and made them focus on more conceptual oriented geometrical tasks. New studies should be designed to examine the effect of newly added graphical elements of Logo on conceptual understanding.

Our new graphical design might affect the curriculum of the elementary geometry and the way geometry is being perceived and taught. Curriculum developers and instructional designers might take our pedagogical concerns into the consideration so that they can benefit from the advantages of our design. Further experimental studies need to be designed to assert our claim.

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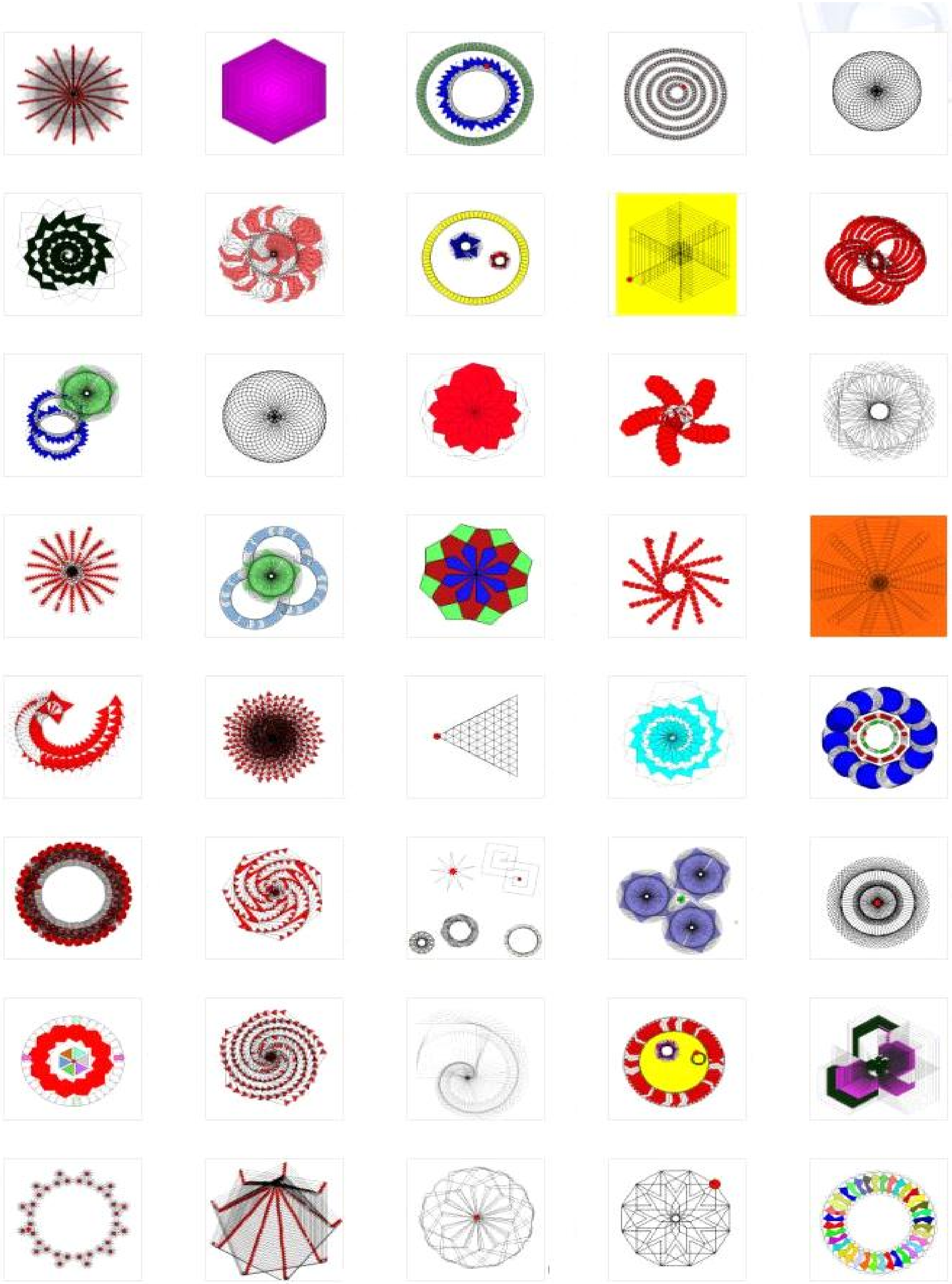
APPENDIX A

Some figures created by using LogoTurk.

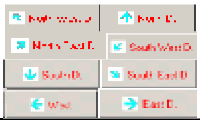
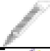
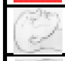
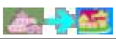
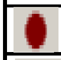
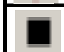


APPENDIX B

Some house figures created by using LogoTurk.

APPENDIX C

Graphical Elements of LogoTurk.

Icons	Logo Comands	Explanation
	Forward ?	Moves Turtle one pace forward
	Back ?	Moves Turtle one pace backward
	-	Moves Turtle one pace to some directions namely nortwest, north, north east, south west, south, south east, west and east
	Setfillcolor [? ? ?] Fill	Fills a closed region with the selected color
	PenDown	Sets the pen mode Down
	PenUp	Sets the pen mode Up
	SetPenWidth ?	Sets the width of the pen to the selected size
	SetPenColor [? ? ?]	Sets the color of the pen to the selected color
	ClearScreen	Cleans the Screen
	HideTurtle	Hides the Turtle
	ShowTurtle	Shows the Turtle
	Left ?	Turns the Turtle to the Left with ? degrees
	Right ?	Turns the Turtle to the Right with ? degrees
	SetScrenColor [? ? ?]	Sets the color of the screen to the selected color
	Label ?	Inserts text at the current location of the turtle
	Setfontsize ?	Sets the size of the font to the selected size
	Home	Sets the Turtle position to home
	-	Sets the current position as the new home for the turtle
	-	A block of commands to produce an arc to the right with a specified arc length
	-	A block of commands to produce an arc to the left with a specified arc length
	-	Specifies the arc length for drawing arcs to the left or to the to right
	-	Specifies the length of hthe pace of the turtle for moving any direction
	-	Adjusts the angle to return for certain directions namely northwest,southwest, northeast and southeast
	-	Starts a macro to define a prodecure
	-	Stops the macro and asks for a name for the procedure
	Penpaint	Sets the paint mode to Penpaint
	Penerase	Sets the paint mode to Penerase
	-	Starts the macro definition
	-	Stops the macro definition

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SCIENTIFIC ARGUMENTATION IN PRE-SERVICE BIOLOGY TEACHER EDUCATION*

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ABSTRACT. This paper discusses the design of an instructional unit examining scientific argumentation with prospective biology teachers. Linguistics and philosophy of science have turned to argumentation as a relevant skill; its importance in science classes has also been highlighted by scholars. We define school scientific argumentation and analyse its components. We present the unit, directed to pre-service biology teachers, which includes different strategies; among them, we propose guided reading, analogies, debates, and discussion on historical episodes. We describe the activities, examining the nature-of-science topics addressed. The sequence relates to secondary science teaching; this may increase the meaningfulness of the nature of science in teacher education.

KEYWORDS. Argumentation, Biology, Components, Scientific Explanation, Nature of Science, Teacher Education.

INTRODUCTION

This paper discusses with some detail the design, and more briefly the implementation, of an instructional unit that aims at examining with prospective biology teachers the skill of scientific argumentation and its importance in science education. We are a team of teacher educators in charge of two consecutive one-semester courses, Didactics of Biology I and II. These compulsory courses are directed to students in the fifth and sixth years of the degree in biology teaching (these students would be more or less equivalent to biology graduates in a masters program in biology education).

We acknowledge the need to introduce contents of the nature of science in science teacher education, as a means to improve their teaching skills and metacognitive awareness (Matthews, 1994; McComas, 1998). We want our future teachers to be able to convey to their

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own students a coherent view on science, its development, its evolution and its relations with society and culture. The ability to do so would comprise both an explicit teaching of nature-of-science models and the integration of these in the presentation of the scientific content.

Our aim is to prepare prospective teachers so that they are able to enhance, in their own students, cognitive abilities or skills that are strongly related to science, but that also belong to any 'rational' activity. In this sense, 'general' cognitive abilities would be those put into action in any rational human enterprise, and science, as a paradigm of this way of thinking, contributes both to the characterisation and to the learning of such abilities (Sanmartí, 2003). In our view, the development of 'scientific' cognitive skills would start from the selection and implementation of particular procedural contents that are able to support them, such as identifying problems, formulating hypotheses, contrasting models, providing evidence, etc.

Recent research on the nature of the scientific language in the classroom has led to identifying scientific argumentation as a topic of key importance in science teacher education (Ogborn et al., 1996; Driver, Newton and Osborne, 2000; Osborne, 2001; Duschl and Osborne, 2002). Argumentation and explanation would be at the very vertex of the 'scientific pyramid' (Duschl, 1990), being the most inclusive and elaborate scientific abilities, in which models are put into action in order to give meaning to the world. This perspective on the role of argumentation/explanation of course denotes the philosophical perspective to which we adhere, the cognitive model of science from the current semantic view (Giere, 1988; Izquierdo and Adúriz-Bravo, 2003).

A broad range of theoretical conceptions on the nature of scientific argumentation is currently available in the literature of science education; these conceptions are mostly derived from classical positions from the philosophy of science or linguistics (including rhetorics). Jonathan Osborne (2001) has thoroughly reviewed educational definitions of scientific argumentation and their epistemological foundations. Consequentely, it is not our intention to repeat such considerations; we rather want to present our own ideas on school scientific argumentation, which we have developed for our practice as science teacher educators.

SCHOOL SCIENTIFIC ARGUMENTATION

Considering science education as acquisition of cognitive skills is in tune with some influent contemporary views on the nature of science, which assume that doing science is not merely performing practical experiences, a position of strong inductivist or empiricist reminiscence, but also, and more importantly, talking and writing about such experiences with particular, and very elaborate, semiotic systems (the scientific lanaguages). Current philosophy of science has turned to argumentation as a skill of major relevance (Toulmin, 1958; Gross, 1990) and consequently the importance of argumentation in the science classes has been highlighted in recent years (Driver et al., 2000; Osborne, 2001). Argumentation as a discursive tool is at the heart of the process of scientific explanation in the classroom.

In order to be able to construct operative models and explanations about the natural world, students need, besides meaningfully learning the involved concepts, to be able to distinguish between different kinds of explanations and to apprehend criteria that enable critical evaluation when choosing between models. In the scientific community, such choice (usually referred to as 'scientific judgement') occurs in a context of debate or controversy; in the classroom, argumentative dialogue is generally enacted through the presentation of opposing positions and the discussion of reasons and evidence supporting them. School scientific argumentation thus establishes a very specific and elaborate kind of oral communication (Jiménez Aleixandre, 2003) and of text production (Sanmartí, 2003).

In our work, we identify to some extent the skills of explaining, justifying and arguing, though some authors from the field of linguistics make distinctions between them based on formal or pragmatic considerations (for instance, it is usually pointed out that arguing as a typical rhetorical procedure implies a strong will to convince). Those three skills have been labelled cognitive-linguistic abilities, since they reflect high-order cognitive capacities but at the same time imply the production of very elaborate oral and written texts (Sanmartí, 2003).

For our teacher education purposes, we define scientific argumentation as the production of a text in which a natural phenomenon is subsumed under a theoretical model by means of an analogical procedure1. Argumentation can therefore be considered as the 'textual' counterpart of scientific explanation.

In a 'complete' school scientific argumentation, we recognise the following elements, which we call 'components':

1. the theoretical element, meaning that there must be a theoretical model (Giere, 1988) as a reference, allowing to explain a phenomenon by its 'similarity' to the model;

2. the logical element, meaning that arguments have a rich syntactic structure and can be formalised as reasoning patterns (for instance: deductive, abductive, analogical, relational, causal, functional);

3. the rhetorical element, meaning that arguments have convincing as an important aim (Osborne, 2001);

4. the pragmatic element, meaning that arguments are situated in a particular communication context from which they take meaning.

The next section of the paper is devoted to presenting a complete instructional sequence directed to pre-service biology teachers that was designed following the guidelines of a theoretical framework previously presented (Adúriz-Bravo and Izquierdo, 2001; Izquierdo and

Adúriz-Bravo, 2003). The sequence amounts to four hours and includes a variety of resources used in individual, small-group and plenary tasks. Among these resources we can mention dramatisation, debates, quizzes, historical episodes, analogies, text analysis, guided reading.

We provide an overview of the complete sequence, describing the different activities. We mention the nature-of-science topics addressed (among them, reasoning patterns and scientific discovery), and we show how these are materialised. An important feature of the sequence is that it always relates to science teaching in the secondary classroom; this increases the potential meaningfulness of the nature-of-science content that is taught to prospective science teachers.

THE INSTRUCTIONAL UNIT

Our instructional unit is structured in three activities, as described below. The activities comprise a series of individual paper-and-pencil tasks followed by small-group and plenary discussion.

Introductory activity: focusing on the problem of argumentation

This activity intends to highlight the relative vagueness that, in natural language, the terms 'describe' and 'explain' have. With this aim, student teachers are presented with an unknown sub-microscopic sample: it is an electronic-microscope image of chromosome crossing-over during prophase I of cell meiosis. The overhead image presented to them has no identification labels on it.

A student is then asked to describe what he/she sees. As the student performs what he/she considers a description, notes are taken on the blackboard. After that, another student is asked to explain what he/she sees. As in the previous step, notes of this 'explanation' are taken on the blackboard.

Then comes a moment of conceptualisation of the task. The notes taken during the previous steps of the activity somehow show that the verbs 'describe' and 'explain' have an ambiguous meaning in natural language. Students required to describe, for instance, usually employ theoretical terms (such as 'chromosome', 'allele', 'meiosis') and introduce hypotheses or other inferences. Students required to explain, on the other hand, usually resort to causal, functional or transdictive2 inferences, or sometimes enumerate sheer characteristics of the image (colour, shape, size).

Other aspects of the problem of describing and explaining in the science classroom are then examined with the class. On the one hand, we distinguish between cognitive and linguistic procedures involved in description and explanation. Subjects need to know how to construct a description or an explanation in their minds but they also need to enact such procedure in a coherent text. We also focus our students' attention on the fact that both abilities pose clearly different intellectual demands, description being much simpler than explanation.

On the other hand, the activity suggests that, when teaching in secondary science classes, it is necessary to make explicit and to share the meaning of these competences, which are often required in the science classes. Therefore, it is necessary to transform them into explicit objects of instruction.

Theoretical activity: examining scientific argumentation

The importance of learning to talk and write science has been receiving increasing attention in the literature of science education (Lemke, 1990; Sutton, 1992). Many authors within this line work from a neo-vygotskian perspective, regarding languages as systems of resources that enable subjects to construct meaning. Accordingly, the natural language is considered to play a central role both in the transmission and in the generation of science.

Neus Sanmartí (2003) uses the label 'cognitive-linguistic abilities' to characterise any one of a set of complex intellectual skills extensively used in the classroom. Such abilities can be associated to different text typologies ('genres') and resort to diverse semiotic registers (speech, writing, figures, images, scale models, gesture...).

A great number of cognitive-linguistic abilities can be identified (describing, summarising, defining, explaining, justifying, warranting, arguing...), even though the precise meaning of each of them cannot be totally ascertained. We classify those in first-order abilities (such as describe, define, narrate, summarise) and second-order abilities (such as justify, hypothesise, refute, explain, argue), suggesting that the latter involve structuring and organising a number of the former.

Arguing has a central role amongst cognitive-linguistic abilities. Given the relevance of scientific argumentation, we think it is important that science teachers teach their own students to elaborate argumentative texts and to identify their components.

Adúriz-Bravo (2004) offers an instructional proposal that aims at working this nature-of-science content using a French film on the life of Madame Curie and what we call the 'invention' of radium3. Student teachers see a sequence of the film in which Marie explains to Georgette, nanny to her little daughter Irčne, the problem she has encountered when trying to account for the irregular radioactivity of pitchblende. Student teachers are required to identify the (oral) texts in which an argumentation takes place and to give examples in which different 'languages' (speech, text on the blackboard, images, gesture) are used in correspondence to the four constitutive components of the argument (theoretical, logical, pragmatic and rhetorical).

Metacognitive activity: reflecting on school scientific argumentation

Initially, we aim at acquainting our students (future biology teachers) with current research on school scientific argumentation. For this purpose, recent investigations by Richard Duschl, Marilar Jiménez Aleixandre, Jonathan Osborne, John Ogborn and other authors are discussed.

We then turn to the role of argumentation in assessment/evaluation. Science teachers often use the formulation 'justify' in their written evaluations with little conscience of its broadness and complexity. As an example to reflect upon, we present our student teachers with actual answers (collected during a previous investigation: Meinardi and Adúriz-Bravo, 2002) to a simulated 'evaluation task': arguing why lice become resistant to 'Nopucid' (an old-fashioned Argentine shampoo against lice). A careful analysis of extremely different answers conveys the idea that the formulation is flawed when argumentation is not clarified, taught and practised beforehand.

The last task of the unit involves working around instructional activities for school scientific argumentation. Student teachers in small groups design an activity, on any biology topic, which would demand from their own hypothetical secondary students the ability of argumentation. Whole-class discussion of the proposed designs asks 'arguing on argumentation': student teachers are required to support their designs referring to the contents covered in the unit. During discussion, 'good' pre-existing examples of the use of argumentation in the secondary classroom are presented and analysed (for instance, Duschl, 1990; Duschl and Osborne, 2002).

The discussion promoted during the set of three activities briefly described above acquaints prospective teachers with some ideas on the nature of science, such as scientific explanation, controversy, pragmatics and abduction. But these ideas are examined through the lens of didactics of science (i.e. science teaching methodology). The aim is to explore the possible usefulness of the nature of science in science teachers' actual professional practice.

FUTURE

Our instructional sequence has recently been put into practice on three occasions with 30 student teachers each time. We have had some informal feeback on its robustness. The proposal has also been adapted for, and implemented with, prospective physics and chemistry teachers. In all these occasions, no systematic data on the pedagogical success of our design has been collected.

Data collection is now being done within a small research project that has just begun. We aim to identify, by means of surveys and interviews, possible substantive changes in teachers' nature-of-sciences conceptions helped by the exposition to the unit.

For this reason, this paper only concentrates on the design of the unit and its coherence with the theoretical framework of reference (Izquierdo and Adúriz-Bravo, 2003). Another important aim is presenting to the science education community our own developments on the idea of school scientific argumentation: definition, classification amongst other abilities and identification of components.

NOTES

1. Many English-speaking authors in philosophy of science and science education (cf. Osborne, 2001) add as a requirement for an argumentation the existence of some form of debate in which two or more opposite views on the phenomenon are confronted and defended. These authors consequently emphasise the rhetorical component of argumentation. In English, the verb 'argue' conveys some idea of confrontation, whereas in Spanish, the corresponding verb 'argumentar' relates more to the idea of providing reasons for the phenomenon, i.e. it somehow implies the production of a reasoning pattern. Thus, in our tradition (stemming more directly from the Latin verb 'arguere', 'to make clear') the logical component is emphasised.

2. By 'transdiction' we mean an explanation which resorts to entities and functions situated at the organisation levels below that of the phenomenon. For instance, we would say that explaining the behaviour of ideal gases in terms of the kinetic-molecular theory is a case of transdiction.

3. The film is Claude Pinoteau's Les palmes de Monsieur Schutz, released in 1997. A version with English subtitles is available on DVD from Fox Pathé Europa.

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