Preparing teachers for cognitive coaching: the case of Physics by Inquiry as an experiential basis for science learning.

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This article proceeds from the premise that teachers should be trained as facilitators of children's cognitive development. As professionals, teachers should have ultimate responsibility for creating and maintaining a science learning environment that promotes intellectual growth. The inadequacy of the present system of preparing teachers is examined and an argument is presented for offering special science courses integrated into a coherent science teacher preparation program also including science methods courses closely linked with extensive school experience. We describe the Physics by Inquiry program as a context for discussing the type of intellectual objectives and instructional methods that should characterize such courses. We highlight the important role of students gaining authentic experiences with the power of real conceptual understanding and subsequently reflecting on (a) the various aspects of knowledge that comprise science learning and (b) the complex support mechanisms that need to be in place in order to facilitate learning in the science classroom. We will illustrate the interdependency of these issues with specific examples from the Physics by Inquiry program.

Keywords: Physics by Inquiry, Science Teacher Preparation.

1. Introduction

It is generally accepted that science education is in serious difficulty on a global scale. In Cyprus, between the eighth and twelfth grades, the number of students who are able to keep up with curriculum objectives drops by more than 50%. When achievement is compared, Cypriot students perform significantly below the international average at all grade levels [26-28]. Internationally, performance measures repeatedly demonstrate disappointingly low achievement in tasks that require fundamental understanding, systematic reasoning or creative thinking.

There are surely many aspects of our educational systems that contribute to this problem. They include the lack of adequate support for our teachers, the complex expectations from a single profession that translate into unrealistic expectations from individual teachers and the excessive standards that are routinely specified by our societies. All these aspects contribute to a global culture of largely ignoring the essential aims of science education in favor of finding ways to bypass the learning process at all levels of the educational system. Another such aspect that is commonly ignored is the failure of the scientific community that is concerned with education to formulate established terminology and procedures that it can then use as a basis for making progress. The cultural tendency of this community to be more political than technical (falsely justified as being in the interest of political correctness and humanitarian ethos) has tended to make it prone to continual re-invention of past practices and new fads. It has also largely prevented it from gradually weaving scientific expertise with widely recognized and respected applicability. This article focuses on one facet of the current crisis: the failure of our universities to provide the type of preparation that pre-college teachers need to teach science effectively. The discussion is in terms of physics, but the situation in other sciences is similar.

1.1 The problem

The problem of inadequate teacher preparation extends throughout the spectrum from kindergarten to high school [11]. Lacking the proper background, adequate preparation and the support necessary to teach with enthusiasm and confidence, teachers often pass onto students a dislike of science, especially physical science. With a negative attitude often firmly established by ninth grade, most students do not voluntarily take physics in high school. Failure to do so decreases the likelihood that students will go on to complete a University course in the natural sciences or engineering. On the other hand, taking physics in high school does not necessarily ensure adequate preparation for later study. Incompetent teaching may leave students serious deficiencies early on that are bound to make it increasingly difficult and uninteresting in subsequent years. Poor performance in high school physics not only closes the gateway to a career in physics, but to participation in other science related professions as well as the technical decision making procedures that modern knowledge-based societies rely on for their democratic underpinnings.

The chain of events described above has other serious ramifications. One is the early limitation of opportunity for students who cease to respond to science teaching early in their teen years partly caused by under-prepared teachers. A disproportionately large number of these students belong to groups under-represented in the physical sciences and engineering: minorities and women. The result is unequal opportunity for a large segment of our population and a waste of potential talent that might otherwise increase the pool of students pursuing advanced degrees in science and engineering. This also constrains the degree of public appreciation and enjoyment of science as one of the major aspects of human cultural achievement. The low level of scientific literacy produced by our educational system has another serious consequence [20]. In a democracy, the formulation of national and local policy is highly susceptible to public opinion. Therefore, uninformed judgments on important technological issues may have an effect that extends beyond the scientific community to our entire society. This is the most alarming aspect of the current situation. The consistently poor performance of science students to demonstrate conceptual understanding by applying their knowledge successfully in order to make appropriate predictions in unfamiliar situations and to rely on transferable creative thinking, problem solving and reasoning skills in order to analyze decision making situations will continue to hamper the ability of our societies to make best use of available talent both for technological and cultural advancement.

1.2 The perspective

The perspective taken in this article reflects the cumulative experience of the Learning in Science Group at the University of Cyprus where holistic teacher preparation has been an integral part of a comprehensive program in research, curriculum development and instruction for some years. Our research focuses on investigations of student understanding of physics and on the design, development and research validation of innovative curriculum to promote that understanding. The research results into student understanding are used to guide the development of instructional strategies and activity sequences to develop coherent conceptual understanding by addressing specific conceptual and reasoning difficulties encountered in the study of physics. Curriculum development takes place as an integral part of our instructional program. Our program includes special physics courses for prospective and practicing teachers at all grade levels as well as extended school-based intervention programs for children. Continued international support for years has made it possible to devote a major effort to the production of instructional materials that can be used to teach physics and physical science in pre-college classrooms. Our instructional program takes a holistic approach to teacher preparation and owes its success to committed effort, continuous monitoring and evaluation and above all to careful tuning of four mutually complementary components: science content classes, science method classes, extensive pre-service school experience and support for in-service practice. Our work has benefited immensely from international collaboration, especially with the Physics Education Group at the University of Washington.

2. Suggestions for solving the problem

To help define our point of view, it may be useful first to examine some popular proposals for improving the quality of science education in schools. The remedy most frequently suggested by teachers themselves involves increased financial investment in school laboratories and equipment. Although experiences with physical world phenomena provide the foundation for constructing conceptual understanding, there is little evidence that hands-on approaches per se are more effective than more traditional techniques. In particular, hands-on without minds-on activities routinely deteriorate into recipe routines devoid of any meaning other than getting “the right answer” at the end. To the contrary, there is a lot of evidence indicating that practical work that is conceived as a support measure for demonstrating the origin and applicability of knowledge explained in lecture format is doomed to failure in terms of promoting real student understanding.

A popular recommendation among physicists for increasing the number of good teachers is to offer financial incentives combined with relaxing the requirements in education for certification. Such a change would allow more individuals with a strong background in physics to take up teaching immediately after graduation. Many physicists assume that students who have studied physics at university are adequately prepared to teach the subject well. The experience of many countries, including Cyprus, with appointing teachers immediately after graduation with a first degree in the discipline, does not bear this out. This assumption will be examined in greater detail later in the article.

Some governments have pushed for increased if not total emphasis on practical school experience. Given the state of the art in student science learning outcomes, apprenticeship is hardly a suitable model. Furthermore, technical training tends to emphasize routine administrative procedures with only an indirect influence on quality education, differentiation, flexibility and fulfillment of student potential.

Many governments have recently placed much emphasis on assessment procedures. It is true that student behavior in upper secondary and university education is almost entirely determined by assessment practice. It is also true that traditional assessment procedures tend to be thoroughly inadequate as measures of real student understanding. However this approach rests on the erroneous premise that if ineffective practice is currently determined by assessment, improving assessment procedures can spontaneously improve learning. Indeed quality in assessment may be a necessary pre-requisite but it is also most likely to be an insufficient pre-condition for quality in learning. Furthermore, it has been repeatedly demonstrated that good assessment practice is thoroughly integrated with instructional approaches and is well tuned both with the range of abilities among examinees and with the content of the course including all pre-requisites, an issue that is commonly underestimated.

A popular recommendation among education professionals for improving the quality of science learning is to increase the requirements for pedagogical training of science teachers. The rationale relies on psychology, sociology and philosophy providing a framework for these teachers to be able to critically analyze the development of individual needs, classroom situations and school environments so that they can then develop appropriate interventions with a high degree of personal ownership. Alas, an operational framework of this kind has never been properly conceptualized by education scientists. Partly as a result, there is little or no evidence that the traditional foundation subjects actually influence classroom practice in any substantial manner. Only exceptionally talented students are able to bridge theory in any of the foundation disciplines to influence practice. The question of identifying what type of transformation is required to synthesize aspects of the foundation disciplines into principles that can influence actual classroom practice still remains largely unresolved by contemporary research.

Another proposal involves entry into the classroom of technically trained professionals as teachers. In some countries, a small but significant number of scientists and engineers are opting for mid career and late career shifts into teaching. It is taken for-granted that the technical competence of these individuals ensures that they have the necessary command of the subject to be effective teachers. However, working in industry does little to develop the requisite depth of understanding, either of the subject matter or of the learning process. Practical experience is usually sufficient for carrying out day-to-day duties. Furthermore, during the years of industrial employment, the scientist or engineer has been away from the school environment and is likely to be less aware than a classroom teacher of the special difficulties physics presents to students.

Volunteer teaching in the classroom by scientists and engineers has been suggested as an alternative way of improving the quality of pre-college science education. Such efforts can be highly motivational to young students in the short term, but occasional or intermittent visits are unlikely to result in sustained long-term learning. Experience has also shown that volunteers seldom succeed in leaving the teacher better equipped to teach science independently. Indeed, very often the result of having a visitor in the classroom is to provide relief for the teacher, who turns attention to other matters.

The measures discussed above are simple in concept and in many places could be implemented relatively quickly, provided financial and administrative complications could be resolved. However, such remedies are temporary at best and usually cannot be applied on the scale of an actual educational system. It is essential that teacher preparation be a major focus in any effort at reform.

An effective teacher education program must take into account the needs of two different populations: (1) prospective (or pre-service) teachers who are not yet certified and (2) practicing (or in-service) teachers who are already in the classroom. Pre-service teachers have the flexibility to attend day courses at the university. However, in-service teachers have less flexibility and may be unable or unwilling to participate in a standard instructional program unless special arrangements are made. Important differences also exist in the preparation needs of elementary and secondary teachers.

The emphasis in this article is on the subject matter preparation of both pre-service and in-service teachers. We have concentrated on science as an example even though much of the discussion relates to other disciplines as well. Throughout the discussion, the word “teachers” refers to both prospective and practicing teachers; the modifiers “pre-service” and “in-service” are reserved for cases in which a distinction needs to be made. The only aspects of in-service teacher education that are considered are those that can be addressed through the regular departmental structure of a college or university. No attempt is made to give an overview of the variety of in-service programs.

3. Traditional approach to teacher preparation

In recent decades it is common for pre-college teachers to be educated in the same universities as the general population.

In Cyprus, prospective secondary teachers must complete a Bachelor’s degree in the discipline and also obtain certification by completing the requirements of a seven month pedagogical training program. In many countries, two independent administrative units are involved in the process of producing science teachers: a department or school of education and a school of sciences (or equivalent). Faculty in education offer courses on methodology and on the psychological, social and cultural aspects of teaching and learning. Faculty in the sciences offer courses on the subject matter. In Cyprus, the situation is even more disparate since two independent institutions are involved: the University of Cyprus offers the Bachelor’s programs and the Pedagogical Institute is responsible for the pedagogical training. In primary education the situation is much simpler. Prospective kindergarten and elementary school teachers must simply complete a four year Bachelor’s degree in Education offered entirely by the

Department of Educational Sciences at the University of Cyprus.

3.1 Traditional Program Design

Most teacher preparation programs, whether for prospective primary or prospective secondary teachers, consist of varying proportions of subject matter content, educational research methods, psychological, social, philosophical and cultural foundations of teaching and learning and a period of school practice [5]. As indicated by the common requirement for a discipline - based first degree, the greater emphasis in secondary education is on subject matter content. Primary education often presents a more equal and far wider representation of the different components. However, even here the content coverage tends to be immensely broad in the hope of producing multi-dimensional professionals that are capable of teaching any discipline at this age level. The underlying premise that *a good teacher can teach anything* continues to plague the programs offered by education departments the world over.

The greatest shortcoming of traditional teacher preparation programs at both levels is fragmentation and lack of coordination. The courses are offered by scientists specializing in the different disciplines, often in the same department but sometimes not. Hence, teacher educators often hold variable cultural values and very different priorities with little or no incentive to collaborate in order to make the overt connections that are necessary for students to build a coherent whole out of the different aspects. Students often simply perceive an immense breadth in coverage with little opportunity for in-depth analysis or critical application. In the eyes of the students, the fragmentary presentation of the disciplines invariably reduces to a series of assessment hurdles that students have to overcome before getting certification. It is extremely rare to witness a situation where a student is able to synthesize the operational understanding necessary to make appropriate decisions on developmental appropriateness, group management and adaptability in motivating and rewarding students. Good teachers develop some of these characteristics after years of experience and only in particular contexts.

3.2. Inadequacy of the traditional approach in Physics Departments

Subject matter preparation for teaching science is often distributed among the respective discipline departments. Prospective science teachers generally take standard departmental courses. Usually no special attempt is made to take into account the needs of these future teachers.

Many science faculty seem to believe that the effectiveness of a pre-college teacher will be determined by the number and rigor of courses taken in the discipline. This attitude seems to prevail in most physics departments. Accordingly, the usual practice is to offer the same courses to future teachers as to students who expect to work in industry or to enter graduate school. However, traditional physics courses generally do not provide the type of preparation that teachers need nor do they meet the needs of people who will be guiding the development of student understanding. The breadth of topics covered in the typical introductory physics course allows little time for acquiring a sound grasp of the underlying concepts or of linking them with applications to real life phenomena. Ordinarily, no special effort is made to address the common conceptual and reasoning difficulties that prospective teachers, like other students, encounter. The lecture format encourages passive learning. Students become accustomed to receiving knowledge rather than helping to generate it. The emphasis in these courses tends to be on solving traditional exercises through application of formulae rather than on the conceptual understanding that is a crucial pre-requisite to teacher effectiveness. This routine algorithmic problem solving that often characterizes introductory physics courses does not help teachers to develop the reasoning ability necessary for handling the unanticipated questions that are likely to arise in a classroom situation.

The laboratory sequence that often accompanies the introductory physics course also does not address the needs of teachers. Often the equipment used is not available in the teachers' schools and no provision is made for showing them how to plan laboratory experiences that utilize simple apparatus. A more serious shortcoming is that experiments are mostly limited to the verification of known principles. Students have little opportunity to make observations and perform the reasoning involved in formulating these principles. As a result, it is possible to complete the laboratory course without confronting conceptual issues or understanding scientific processes.

The most worrying outcome of science content courses is not that our students emerge without good understanding of many science topics. Often prospective teachers emerge with a misconstrued notion of what it means to understand and how one would go about developing good understanding. By definition, students who have not come to a fundamental appreciation of the nature of conceptual understanding in science through experiencing understanding themselves, cannot be helped by science methods courses.

A year of introductory university physics is admittedly insufficient for preparing science teachers. However, it does not follow that advanced physics courses provide useful preparation for teaching, either. The abstract formalism that characterizes upper division courses in physics is not of immediate use in the pre-college classroom; neither are the complicated experiments and sophisticated equipment of advanced laboratory courses. Although work beyond the introductory level may help some teachers deepen their understanding of physics, no guidance is provided about how to make appropriate use of this acquired knowledge in teaching younger students.

Sometimes, in the belief that teachers need to update their knowledge, a university instructor may give a lecture course on contemporary physics. Such courses are of limited utility. The information may be motivational but does not help teachers recognize the distinction between a memorized description and substantive understanding of a topic.

3.2 Inadequacy of the traditional approach in Education Departments

Sometimes content courses are offered within education departments, particularly in the case of primary teacher training programs. Often these have similar disadvantages for teachers as undergraduate courses offered by the other departments. To help fill the gaps in background and to match school curriculum coverage, instructors often attempt within a short period of time to present a large portion of the content covered in a traditional physics course. There seems to be a tacit assumption that if the material is well organized and clearly presented, teachers will be able to absorb the information quickly and disseminate it to their own students. However, the amount of material and the rate of presentation may be so overwhelming that learning is impossible at any but the most superficial level.

Content courses taught by education departments often have an additional disadvantage. In education we use the term theory somewhat more freely than is common practice. For instance, we do not require our learning theories to have predictive capability that can be checked at the classroom or individual level. In addition, science education has suffered from complete domination of the constructivist paradigm as an all encompassing theory of learning that for many years has been beyond dispute. In this context, science educators are often keen to apply their "theory", usually some version of constructivist strategy, to their teaching. The consistency in thinking that transcends the researcher and teacher roles is admirable. However, when theory is reduced to blind strategy, with little or no evidence of effecting real learning, it can have a detrimental effect both on the course and on prospective teacher perceptions of science education as an enterprise aiming to promote science learning. One common example of this detrimental influence is the indiscriminate application of cognitive conflict as a classroom strategy. While usually justified as a constructivist strategy, it often tends to leave the student in despair at the perceived pleasure that their instructors take out of student ignorance. In contrast, the constructivist paradigm could be viewed as a basic principle that characterizes human learning and has important implications for the design of teaching interventions. This principle could then inform strategies for developing curriculum and other resource materials that teachers badly need in order to respond to the challenges and the level of responsibility we expect of them.

The total separation of instruction in methodology from instruction in content decreases the value of both for teachers. Effective use of a particular instructional strategy is often content specific. If teaching methods are not studied in the context in which they are to be implemented, teachers may be unable to identify the elements that are critical. Thus they may not be able to adapt an instructional strategy that has been presented in general terms to specific subject matter or to new situations. The consequences of underestimating the amount of teacher preparation needed for implementation of a new science curriculum has been demonstrated repeatedly with various reform initiatives that have been undertaken from time to time. Even detailed directions cannot prevent the misuse of excellent instructional materials when teachers do not understand either the content or the intended instructional approach.

The traditional approach to teacher preparation has another major shortcoming. Teachers tend to teach in the same way as they have been taught. If they have learned through lecture, they will essentially lecture to their own students, even if this type of instruction may be inappropriate. Many teachers cannot, on their own, separate the physics they have learned from they way in which it was presented to them. It is especially unrealistic to expect large adjustments in instructional approach if teachers must teach material soon after having learned it themselves. Even very able teachers, who eventually might be able to adapt content learned through lecture to activity-based instruction, cannot be expected to do so quickly.

More crucially, both science courses for teachers and curricular specifications for schools are often concept centered and ignore other important aspects of science such as reasoning and procedural skills, epistemological awareness and evidence-based decision making. This commonly leads to erroneous understanding of the nature of science and hence a misconstrued conception of its teaching. The model of science that teachers commonly adopt as a result of our courses is incongruous both with the nature of science as a process of inquiry and with effective science learning.

4. Development of holistic programs for science teachers

A well-prepared teacher of physics or physical science should have, in addition to a strong command of the subject matter, knowledge of the difficulties it presents to students as well as expertise and experience with identifying patterns in student thinking and in formulating appropriate sequences of questions to guide their students in further developing their thinking [9]. To counter the public perception that physics is extremely difficult, the teacher must be able to teach in a way that allows students to achieve adequate mastery of the topics studied and confidence in their ability to understand and apply what they are learning in their daily life. Since neither traditional physics courses nor foundation or professional education courses can provide adequate preparation for pre-college teachers, there is a need for a new conceptualization of our teacher preparation programs including in particular special science content courses for teachers [21]

In an effort to meet this need at the University of Cyprus, we completely redesigned from first principles our science teacher education program. The program described here was implemented for the first time as a whole in the 1998-99 academic year within the elementary education program offered to a total of 600 students at any one time by the Department of Educational Sciences. The program includes special science content courses specifically designed to meet the background knowledge needs of primary school teachers [13]. These courses are carefully linked to science method courses and a specially designed school practicum structure to enable implementation and continued refinement of a structured conceptualization of science learning and its facilitation in a formal environment that identifies and nurtures differentiation in a collaborative forum.

The special science content courses for teachers have provided an environment in which we can empirically refine our understanding of their academic needs. We originally used the insights gained by researchers elsewhere [15] to define substantial objectives for such courses [14]. We then designed a structure that allows us to continuously monitor the evolving nature of our understanding of these needs and the effectiveness of our conceptualization at any one time in promoting quality in the preparation of our teachers. In addition to the instructional function, all our courses have provided a context for research on the nature and facilitation of the learning and teaching of physics and a setting for the development of structured curriculum to promote these aspects of teacher preparation in a systematic manner [30].

The following commentary is a distillation of what we have learned and what we are currently trying to implement [12, 17-19]. The discussion below is not an exhaustive summary of all that should be done to prepare teachers. Practical matters, such as laboratory logistics and classroom management are not addressed. The focus is on intellectual aspects.

4.1 Intellectual objectives

Initial courses for teachers should emphasize the content that the teachers are expected to teach. A primary intellectual objective should be a sound understanding of important concepts and their formal representations. Equally critical is the ability to perform the reasoning that underlies the development and application of both concepts and representations. Conceptual understanding and capability in scientific reasoning provide a firmer foundation for effective teaching than superficial learning of more advanced material. Teachers should be given the opportunity to study introductory physics in depth, beyond what is possible in a typical introductory physics course. They need to examine the nature of the subject matter, to understand not only what we know, but on what evidence and through what lines of reasoning we have come to this knowledge [22].

Teachers should develop proficiency in both quantitative and qualitative reasoning. It has been demonstrated that university students enrolled in the standard courses often lack certain basic skills, such as the ability to reason with ratios and proportions and to describe the line of reasoning that has led them to a stated conclusion [22]. Courses for teachers should cultivate these skills, which tend to be overlooked in traditional instruction. Also important is the development of facility in the use and interpretation of scientific representations, such as graphs, diagrams, and equations. If they are to make the formalism of physics meaningful to students, teachers must be adept at relating different representations to one another, to physical concepts, and to objects and events in the real world.

Teachers must be able to solve the types of problems that are included in the typical introductory physics text. However, the main emphasis in a course for teachers should not be on acquiring facility with mathematical manipulation nor on developing procedures for precise determination of fundamental constants. As necessary as quantitative skills are, ability in qualitative reasoning is even more crucial. For example, teachers should be able to distinguish observations from inferences and to do the reasoning necessary to proceed from observations and assumptions to logically valid conclusions. They need to recognize what is considered evidence in physics and what is meant by an explanation. They must recognize the difference between naming and explaining. Problems in which the use of mathematical formalism alone suffices for a solution are not effective measures of conceptual understanding. Thus, instead of concentrating on the type of algorithmic problem solving that characterizes most physics courses, the instructor should assign problems that require careful reasoning and should insist that an explanation of the reasoning be part of the solution. Explanations of reasoning should form crucial aspects of any assessment. Careful analysis of student answers should provide feedback to instructors and students alike as to the development of student understanding and the various conceptual, reasoning and epistemological difficulties that tend to arise along the learning pathways of individual students.

An understanding of the scientific process should be an important objective in a course for teachers. The scientific process can only be taught through direct experience. An effective way of providing such experience is to give teachers the opportunity to construct a scientific model from their own observations. Teachers should go through the step by step process of making observations, drawing inferences, identifying assumptions, formulating, testing, and modifying hypotheses. The intellectual challenge of applying a model that they themselves have built (albeit with guidance) to predict and explain progressively more complex phenomena can help teachers deepen their own understanding of the evolving nature, use, and limitations of a scientific model. Furthermore, we have found that successfully constructing a model through their own efforts helps convince teachers (and other university students) that reasoning based on a coherent, consistent model is a far more powerful approach to problem solving than rote substitution of numbers in memorized formulae.

In addition to the instructional objectives discussed above, which in principle are equally appropriate for the general student population, teachers have other requirements that special physics courses should address. For example, it is particularly important that teachers learn to express their thoughts clearly. The indiscriminate use of words that have both technical and common meanings hinders development of conceptual clarity. Teachers need practice in formulating and using operational definitions. To be able to help students distinguish between related but different concepts (e.g., velocity and acceleration, mass and volume, heat and temperature), they must be able to identify in words precisely and unambiguously what the significant differences are.

Teachers must also be able to anticipate common conceptual difficulties that students are likely to encounter in the study of a topic in physics or physical science. Such information may come from the teachers' own experience in learning the material or, if they have avoided the usual pitfalls, through knowledge of results from research in physics education and through careful and continuous monitoring of the development of their own students' understanding. To help students overcome specific difficulties, teachers need to be familiar with instructional strategies that have proved successful and that are likely to be effective with pre-college students. Again, direct experience is one way of gaining such knowledge; another is through awareness of research.

Courses for teachers should also help develop the critical judgment necessary for making sound choices on issues that can indirectly affect the quality of instruction. For example, teachers must learn to discriminate between learning objectives that are meaningful and those that are trivial. When instruction is driven by a list of objectives that are easy to achieve and measure, there is danger that only shallow learning will take place. Memorization of factual information often falls in this category.

Teachers need a framework for evaluating instructional materials, such as textbooks, laboratory equipment, and computer software. They should become familiar not only with the most popular texts, but also with others that the instructor considers exemplary. They should recognize the strengths and weaknesses of using the computer in various ways (e.g., simulations, microcomputer-based laboratories, interactive tutorials) [23]. Aggressive advertising and an attractive presentation often interfere with objective appraisal of intellectual content. We have observed teachers react with enthusiasm to an appealing format, while they ignore serious flaws, such as developmentally inappropriate objectives, inadequately sequenced content and a lack of accuracy in physics [4].

The ability to make wise decisions on matters such as the foregoing is important since, through service on professional committees, individual teachers can often have an impact that extends beyond their own classrooms. A poor curriculum decision can easily deplete the small budget most schools or even educational systems have for science without resulting in the anticipated improvement in the quality of the learning experience for students and the instructional experience for teachers.

4.2 Instructional methods

Teachers should be prepared to teach in a manner that is appropriate for the pre-college level. Science instruction for young students is known to be more effective when concrete experience establishes the basis for the construction of scientific concepts (1, 2). We have found, as have others, that "hands-on" laboratory investigations guided by appropriate questions also help foster concept formation at the college level. Therefore, in addition to learning how to teach their own students most effectively, teachers benefit directly from instruction that is centered in the laboratory.

The curriculum used in physics courses for teachers should be in accord with the instructional objectives. If the capacity to teach "hands-on" science is a goal of instruction, then teachers need to work through a substantial amount of content in a way that reflects this spirit. However, there is another compelling reason why the choice of curriculum is critical. We have found that teachers often try to implement instructional materials in their classrooms that are very similar to those which they have used in their college courses. Even though it has not been our intent to have young students work directly with the materials that have been developed specifically for teachers, the curriculum has been used in this way.

Whether intended or not, teaching methods are learned by example. The common tendency to teach physics from the top down, and to teach by telling, runs counter to the way pre-college students (and many university students) learn best. The instructor in a course for teachers should not transmit information by lecturing. However, neither should the instructor take a passive role, but instead should assume responsibility for student learning at a level that exceeds delivery of content and evaluation of performance. Active leadership is essential, but in ways that differ markedly from the traditional mode.

The instructor's role is characterized below by a few examples that are described in general terms. Instructional strategies in the context of specific subject matter are illustrated, either explicitly or implicitly, in several of the references that are cited in the article [8, 10].

The study of a new topic should begin with an opportunity for open-ended investigation in the laboratory in which teachers can become familiar with the phenomena to be studied. Instead of introducing new concepts or principles in the customary manner by definitions and assertions, the instructor should set up situations that suggest the need for new concepts or the utility of new principles. By providing such motivation, the instructor can begin to demonstrate that concepts are created as useful scientific tools and concept formation is a process in which the student must be actively engaged. Generalization and abstraction should follow, not precede, specific instances in which the concept or principle may apply. Once a concept has been developed, the instructor should present the teachers with new situations in which the concept is applicable. This process of gradually refining a concept can help develop an appreciation of the successive stages that individuals must go through in developing a sound conceptual understanding.

As the teachers work through the curriculum, the instructor should pose questions designed to help them to think critically about the subject matter and to ask questions on their own. The appropriate response of the instructor to most questions is not a direct answer, but another question that can help guide the teachers through the reasoning necessary to arrive at their own answers. Questions and comments by the instructor should be followed by long pauses in which the temptation for additional remarks is consciously resisted [24].

A course for teachers should develop an awareness of the conceptual and reasoning difficulties likely to be encountered by students. For example, research has helped identify numerous alternative ideas that are usually discrepant with the formal concepts of physics [16]. Some of these ideas result from a misinterpretation of daily experience [6], others from a misunderstanding of formal instruction [7]. Regardless of origin, certain alternative conceptual schemas are at such a fundamental level that, unless they are effectively addressed, meaningful learning of the relevant content is not possible. Teachers should learn to recognize such alternative conceptual frameworks and routinely use these as points of departure for their teaching. More recently, research has also shown that, during learning, a number of difficulties emerge that hamper students' efforts to construct meaningful knowledge. Teachers should also learn to recognize these difficulties and gain practice in implementing effective activity sequences for guiding students to overcome such obstacles to their learning [25].

Mere discussion of research findings, an approach that is often taken in Education departments, is not sufficient for this purpose. Teachers need to work through the material and have the opportunity to make their own mistakes. When student difficulties are described in words, teachers may perceive them as trivial. Yet from experience we know that often these same teachers, when confronted with unanticipated situations, will make the same errors as students and will themselves encounter persistent difficulties that will need to be overcome if an operational understanding is to be constructed.

Exposure to findings of research should also include critical examination of instructional strategies designed to address specific difficulties. The instructor should illustrate these strategies as the opportunity arises during the course. If possible, the discussion of a specific strategy should be postponed until after it has been used in response to a discrepant event that has actually occurred. Teachers are much more likely to appreciate important nuances through an actual example than through a hypothetical discussion. Without specific illustrations in the context of subject matter with which they are thoroughly familiar, it is difficult for teachers to envision how to translate a general pedagogical approach into a specific strategy that they can use in the classroom. Teachers need extensive practice in addressing common difficulties and in guiding learning procedures and this practice needs to be firmly grounded in their own learning experiences of science topics.

It is not only poorly prepared teachers who can profit from the type of instruction described above. Those with a strong background can also benefit. The experience of working through carefully structured curriculum that is validated through research can help all teachers identify the difficulties their students may have. Those who understand both the subject matter and the difficulties it poses for students are likely to be more effective than those who know only the content. Moreover, unless teachers have experience with learning science through active inquiry, they are unlikely to foster this behavior in students.

4.3 Illustrative course structure

The brief description below of the science component of the elementary teacher education program at the University of Cyprus shows how we have addressed some common administrative problems. Although special courses for teachers can be organized in a variety of ways, the example illustrates an arrangement that has worked well with large student enrollment within a department of education that is part of a research-oriented university. The specific details are not essential for implementing the intellectual objectives and instructional methods discussed above.

At present, six semester-long pre-service courses have been developed to accommodate students with a wide range of previous preparation. Each course meets for 6 hours a week in a laboratory setting.

Two of the courses are designed as content courses placing greater emphasis on the development of conceptual understanding by teachers themselves in very specific subject matter areas. There are no prerequisites other than moderate facility with arithmetic and algebra. Often in one of these courses we focus on observational astronomy where teachers can carry out the whole process from collecting original data to defining useful concepts to constructing explanatory models that allow them to predict when and where they can see the moon and what phase it will be in. Astronomy is a useful initial motivator for two reasons: many of our students have not taken formal instruction in this topic before and are often intrigued by it; many of us have direct experience with many astronomical phenomena such as sunrise and sunset and the phases of the moon, yet only few of us have constructed explanatory models that allow us to use the sun to orient ourselves or to make predictions on the direction of the moon at different times or on the time of moonrise for different days. As such, astronomy is pedagogically useful as a context for illustrating the process of developing conceptual understanding by starting from evidence and using logical reasoning. In other content courses we teach topics such as light and shadow, electric circuits, magnetism and heat and temperature. In all these courses, even though the emphasis is on developing understanding by the teachers themselves, we continuously model a teaching approach which we call *Physics by Inquiry*. In this approach the curriculum provides the structure for student work. Teachers working through the curriculum have to make decisions on what to investigate, what equipment they will need, how to represent and make sense of their measurements, what concepts to define and how to use their understanding to make predictions. In this type of semi-structured inquiry, we as instructors function as facilitators listening carefully to student ideas and using semi-socratic dialogues to ask sequences of carefully structured questions to guide student thinking. We always respond to a questions with another questions, routinely referring the teachers to their experiments and to their reasoning for finding answers. This is the same instructional approach that we are also adopting in the school science curriculum that we are developing through a concurrent research program. Our students know this and are encouraged to participate in our curriculum design and development efforts as part of the third compulsory course, the teaching methods course. At the end of the two compulsory content courses, students with previously negative experiences and

The teaching methods course serves as a reflective opportunity on their own learning but also as a bridge for formalizing, generalizing and transferring some of their own experiences with developing meaning into classroom practice. The course bridges over two gaps: the gap between their own experience with developing conceptual understanding and ways of implementing science as a process of inquiry and the discrepancy between science content courses at the University and routine practice in schools to which they become exposed during the subsequent school practicum. Teachers gain practical experience in addressing common difficulties and in guiding learning procedures through examples of specific learning strategies. As a preparation for the school practicum, students encounter and practice specific ideas for assessing conceptual understanding and use these to evaluate the effectiveness of teaching interventions through a systematic observation protocol that has been developed and validated over the years. They are thus equipped with the necessary armor to face the school system with purpose on the one hand, but skillfully avoiding controversy by always documenting their ideas and approaches on the other.

These compulsory courses are supplemented with two elective courses on school based research and evaluation and on communication and information technology for science learning. These courses are taken by 20-25% of our enrolled pre-service elementary teachers and aim to prepare specialists who are able to function as science resource teachers within a school district.

The school practicum in science takes place over a nine-week period and is taken as an opportunity for our students to put into practice inquiry based science and gain feedback as to the effectiveness of their implementation. In the mentor training program we emphasize use of the same classroom observation protocol as an instrument for providing feedback to our students. We also emphasize the importance of flexibility and the need for allowing pre-service teachers room for experimentation. The emphasis is more on implementing suitable strategies for knowing the extent to which a classroom intervention has been successful rather than on discussing particular content or approach which tends to take on an aura of evaluation that does not help the students need for confidence building. In the preparation period for students, we emphasize the importance of understanding the substantial learning objectives of every lesson and the importance of carefully designing questioning strategies that can guide children to reason for themselves and to develop the skills for autonomous investigative initiatives and control over their learning. In terms of classroom strategies we also emphasize the importance of giving children physical and temporal space to design their thinking approach and to reflect on their efforts. Teachers learn to intervene rarely, gradually and methodically with the sole aim to attain group and classroom convergence on learning outcomes.

One of the things we do not emphasize in our teacher training program are approaches to science curriculum development even though that is central to our research interests. The reason for this is a fundamental belief that effective curriculum development can only take place as a process of research undertaken by a multidisciplinary team involving teachers, curriculum specialists and scientists. We firmly believe that it is unrealistic to expect teachers to design their own lessons and at the same time expect those lessons to support quality and innovation in student learning.

5. Conclusion

The present difficulties in physics education can have serious consequences for the future of the knowledge society. The effect on the greatest number of students is during the pre-college years, particularly the late elementary and early middle school years. The point of view taken in this article is that improvement can take place only when the underlying problem of inadequate teacher preparation is successfully addressed. The debate about teachers as scientists in contrast with teachers as technicians, that has accompanied the transfer of teacher preparation from colleges to universities, has proven too simplistic and polarized. The type of instruction that can meet the needs of teachers is not available in the standard courses offered in most physics, other science or education departments. The traditional University structure of administering these courses as determined by course enrollments, credits, and grading standards encourages too much fragmentation and a general lack of coherence in seemingly disparate activities such as science content, teaching methods and school practicum courses. An effective mechanism for accomplishing this task is through special courses that aim for coherent, wholesome teacher preparation with a clear view of what is manageable by single individuals and what support they need to rely on to promote quality in education. The emphasis in these courses should be on preparing individuals to implement research-based curriculum promoting science as a process of inquiry by acting as cognitive coaches. Providing original experiences with developing meaning and conceptual understanding through inquiry and developing questioning and other skills related to facilitating learning and cognition should figure prominently in the objectives of any teacher preparation course.

The argument presented above has an important implication for university departments. It is unrealistic to expect faculty to dedicate a significant amount of effort to an activity not recognized by the academic reward structure. The general perception in some university departments is that serious teaching effort may even be penalized. The teaching program of a department of education is not the responsibility of its individual members. It is the cumulative responsibility of the common professional identity of the department and should receive communal attention that transcends perceived needs to protect intra-disciplinary boundaries, using as the ultimate reference criterion only the quality of the impact on the educational system as demonstrated by research.

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