Effects of concept maps, semantic networks and computer simulations on students' understandings of quantum physics

Efectos de los mapas conceptuales, de las redes semánticas y de las simulaciones de computadora en el entendimiento de los estudiantes de la física cuántica

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Abstract

This study was carried out with the participation of 128 physics student teachers who attended quantum physics lessons and were taught via traditional instruction methods. Ten questions related to a diagram were given to the students to determine their understanding of some quantum physics' concepts. A six hour course was organized in order to remedy the students' misconceptions by using concept maps, semantic networks and computer simulations. The ten questions were given to the students again two months later in order to determine how the students' understanding had changed. The results have revealed that the teaching strategies and materials used, significantly improved students' understanding of some quantum physics concepts (wave function, reflection, transition, probability flux, transition coefficient, wave constant and wave amplitude). However, the course also improved their understanding of the concepts in quantum physics (transition probability, reflection probability, reflection coefficient, tunnelling).

Key words: *physics education, concept maps, computer simulation, quantum, semantic networks.*

Resumen

Este estudio fue realizado con la participación de 128 estudiantes de licenciatura de física que atendieron a clases de la física cuántica con métodos de enseñanza tradicionales. Diez preguntas relacionadas con temas del curso fueron suministradas a los estudiantes para determinar la comprensión de algunos conceptos de física cuántica. Un curso de seis horas fue organizado para remediar las ideas alternativas de los estudiantes usando mapas conceptuales, redes semánticas y simulaciones de computadora. Las diez preguntas fueron entregadas a los estudiantes nuevamente dos meses más adelante, para determinar cómo ha cambiado la comprensión. Los resultados han revelado que las estrategias y los materiales de enseñanza usados, mejoraron perceptiblemente la comprensión de los estudiantes en algunos conceptos de la física cuántica (la función de la onda, reflexión, transición, flujo de la probabilidad, coeficiente de la transición, constante amplitud de la onda). El curso también mejoró la comprensión de los conceptos en la física (probabilidad de la transición, probabilidad de la reflexión, coeficiente de reflexión, efectos de túnel).

Palabras clave: *educación en física, mapas conceptuales, simulación de computadora, redes semánticas.*

INTRODUCTION

A primary goal of researchers in physics education is to identify potential and actual obstacles to student learning, and then to address these obstacles in a way that leads to more effective learning. The science education literature contains several studies of the students' understanding of scientific phenomena. These studies have revealed that students bring views and explanations of natural phenomena to their learning that differ from the views held by science (OSBORNE, 1982). A major focus of a science course is to help the students recognize whether or not they understand the basic concepts (MCDERMOTT, 2003). Many techniques have been developed to explore learners' cognitive structures and to organize knowledge as described in PREECE (1978). Semantic networks (QUILLAN, 1967), roundhouse diagrams (TROWBRIDGE & WANDERSEE, 1998), concept circles (WANDERSEE, 1987), Vee diagrams (NOVAK & GOWIN, 1984) and concept maps (NOVAK & GOWIN, 1984; NOVAK, 1998) are just a few of them. In science education, concept maps and semantic networks have been used mostly in the study of biology (SCHMID & TELARO, 1990; BRISCOE & LAMASTER, 1991), chemistry (ZOLLER, 1990; WILSON, 1996; MARKOW & LONNING, 1998) and physics (PANKRATIUS, 1990; ROTH & ROYCHOUDHURY, 1993).

Learning is an active process and requires students to construct their own personal schema to assimilate new concepts (YAGER, 1991). To assist in this construction process, scientific models are valuable tools because they can be used to make sense of abstract, difficult and non-observable scientific concepts to accommodate the explainer and audience, the content and context (TREAUGUST & HARRISON, 1999).

Two primary functions of scientific models in teaching are their predictive power and their ability to provide insight into the fundamental nature of the phenomena (BHUSHAN & ROSENFELD, 1995). Scientific models are tools for prediction and correlation, although their potential is not always fully used in the classroom. Nevertheless, recent advances in technology have brought computer modeling and simulations into the realm of everyday life; so that many students experience simulation games, test their own ideas in strategy games, and fly planes by means of computer simulation (TREAGUST, CHITTLEBOROUGH & MAMIALA, 2002). Simulations provide an opportunity for observation, concept development and logical analysis by posing questions and giving opportunities to note patterns in relationships. The use of a simulation involves the students in some of the process of science, in which they may: (1) identify the problem, (2) ask questions and formulate hypotheses and (3) devise and design experiments. Careful experimentation using simulation allows the user to construct a qualitative understanding of behaviour of the system, which can be developed into a qualitative analysis by the more able students.

In this study, a six hour course was planned to determine how the students' (who had taken a quantum physics course previously) comprehension some concepts (wave function, reflection, transition, probability flux, wave constant, wave amplitude, transition probability, reflection probability, reflection coefficient, transition coefficient and tunneling) in quantum physics is altered by the use of concept maps, semantic networks and computer simulations in the course process.

METHODOLOGY

The study was carried out with 128 physics student teachers who had attended classes on quantum physics which were taught via traditional instructional methods in the Ziya Gökalp Education Faculty of Dicle University in Turkey.

The traditional method of instruction is a teacher-centred method by which topics are taught by a teacher theoretically and explained via examples and figures. Students tend to be generally passive and listeners only. The following ten issues related to figure 1 were put to the students to determine their levels of accurate comprehension of quantum physics concepts concerning structure, transition and reflection of matter waves during the transmitting and reflecting processes to a potential step.

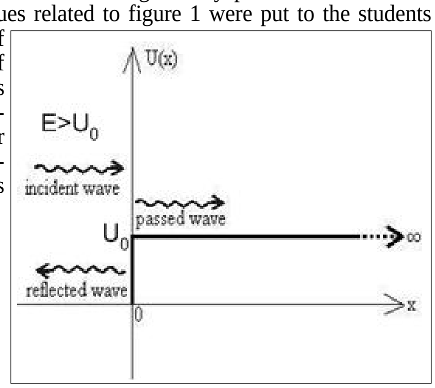

Figure 1. A potential step with finite height and infinite width potential barrier.

Questions given to the students

1) Find the probability flux of the matter wave in front of the potential step.

2) Explain the physical meaning of the probability flux in front of the potential step.

3) Find the probability flux of the matter wave at the potential step zone.

4) Explain the physical meaning of the probability flux at the step zone.

5) Calculate the reflection coefficient by the means of the wave constants.

6) Why is the reflection coefficient not equal to zero?

7) Calculate the transition coefficient by means of the wave constants.

8) Why is the transition coefficient not equal to one?

9) Find the sum of the reflection and transition coefficients and comment on the results.

10) How would the matter wave behave if the energy of the incident matter wave is smaller than the height of the potential?

The students' responses to the above questions were evaluated. The ratio and number of students giving correct responses were determined for each question.

A six hour course was then organized in order to determine how the students' understandings of the reflection, transition, probability flux and wave nature of the matter concepts would be affected by using a different teaching strategy that employed tools such as simulations, concept maps and semantic networks.

The course was conducted as follows:

- Students involved in the course were divided into three groups of 43, 43 and 42 respectively. The reason of dividing 128 students into three groups was that each classroom would hold about 40 students.
- The course was taught by same lecturer.
- The course was conducted between 8.00 and 11.30 o'clock am.
- The course was completed in two consecutive days for each group.

Table 1

Course outline

Region Time (minute)	Course topics	Teaching and learning activities
In front of potential step	Fundamental postulates of 10 quantum mechanics.	Explaining the fundamental postulates of quantum mechanics.
	Schrödinger wave equation.	Solution of the Schrödinger wave equation. and obtaining the wave function.
	Probability flux.	Calculating of the probability flux.
	Reflection coefficient	Calculating of the reflection coefficient.
	Matter wave properties and physical concepts related to the behaviour of the matter wave.	Designing semantic networks and concept maps related to matter wave, probability density, probability 90 flux, wave constants, wave amplitudes, reflection. Demonstrating computer simulations related to reflection of the incident wave.
		Classroom discussions. 30
Potential step zone	Finite width potential barrier and infinite width potential 10 barrier.	Explaining differences between finite and infinite potential barriers.
	Schrödinger wave equation	Solution of the Schrödinger wave equation and obtaining the wave function.
	Probability flux. 50	Calculating of the probability flux.
	Transition coefficient.	Calculating of the transition coefficient.
	Matter wave properties and physical concepts related to the behaviour of the matter wave.	Designing semantic networks and concept maps related to matter wave, probability flux, probability density, wave constants, wave amplitudes, transition. Demonstrating computer simulations related to transition of the matter wave.
		Classroom discussions. 30

The same questions related to figure 1 were administrated to the 128 students again two months later in order to determine how the students' comprehension had changed with regard to reflection, transition, probability density, probability flux and the wave nature of the matter.

Findings

The results obtained before and after the course are summarized in Table 2. The ratio test was used to test whether the differences in the ratios of students with an accurate comprehension before and after the course were statistically significant or not. The significant results are shown in table 2.

Table 2

The numbers and ratios of students' giving correct responses to the questions before and after the course

Topic related to question	Question number	Before the course		After the course		Z-values
		n	Ratios	n	Ratios	
Calculating probability flux.	1	60	0.468	77	0.601	-2.13*
Explaining physical meaning probability flux in front of potential step.	2	13	0.101	25	0.195	-2.11*
Calculating probability flux.	3	54	0.422	76	0.593	-2.750**
Explaining physical meaning of probability flux at the potential step zone	4	10	0.078	17	0.133	-1.424
Calculating reflection coefficient.	5	38	0.297	52	0.406	-1.833
Interpreting why the value of reflection coefficient does not equal to zero.	6	6	0.047	14	0.109	-1.863
Calculating of transition coefficient.	7	47	0.367	69	0.539	-2.762**
Interpreting why the value of transition coefficient does not equal to one	8	8	0.062	28	0.218	-3.596**
Interpreting the sum of reflection and transition coefficients.	9	39	0.304	47	0.367	-1.059
Interpreting behaviour of matter wave in case of matter wave energy smaller than height of potential step.	10	6	0.047	11	0.086	-1.255

Note: n = Numbers of the students' giving the correct response

* $P<0.05$

** $P<0.01$

DISCUSSION

The results of this study revealed that the course had increased the accurate comprehension ratios for all the quantum physics concepts which were considered (wave function, reflection, transition, probability flux, wave constant, wave amplitude, transition probability, reflection probability, reflection coefficient, transition coefficient and tunelling). This is new and repeated evidence of the reality that modern strategies and technologies should be used instead of traditional methods for more successful teaching and learning.

The teaching strategies and materials used during the course process have significantly increased the accurate comprehension ratios for some quantum physics concepts (wave function, probability flux, wave constant, wave amplitude, transition, transition coefficient and reflection) of the students in comparison with those from before the course (see table 2). These results are in accordance with the findings of many researchers (Novak, Gowin & Johansen., 1983; Hewson, 1985; Thornton & Sokoloff, 1990, 1998). They stated that when semantic networks, concept maps and computer simulations are used in course activities that these techniques give a better understanding of the concepts involved than do traditional methods. The new approaches include simulations, multimedia presentations, and more recently, virtual environments. Computer-based work is useful to visualize physical and chemical processes; allowing for a better conceptual understanding (Trindade, Fiolhais & Almeida, Sep. 2002).

In addition, the course which was conducted also positively affected the accurate comprehension ratios of the concepts (reflection coefficient, transition probability, reflection probability, tunnelling) even though the size of the effect was deemed statistically insignificant. A glance at table 2 shows that these concepts are generally related to physical interpretations of some quantum physics phenomena. Despite the fact that reflection phenomena were understood by the students, the equivalency of reflection coefficients and reflection probability was not comprehended sufficiently. Similar comprehension difficulties were observed for the equivalency of transition coefficients and transition probabilities. In addition, many students had not understood the difference between potential step and potential barrier. Therefore, they believe that tunnelling could occur. It is clear, and to be expected, that physical interpretation is more difficult than calculating the numerical results of some functions and coefficients. On the other hand, the results show that the teaching strategies and materials used in the course are not effective enough to reduce the misconception ratios significantly in relation to the concepts in question. Similar findings about the behaviour of matter wave have been published by McDermott (1984), Johnston, Craford & Fletcher (1998); Vokos, Shaffer, Ambrose & McDermott (2000); Muller & Weisner, (2002). Rebello & Zollman (March, 1999). They reported that with the use of hands-on and visualization instruction materials, students have acquired a good general understanding of some important quantum concepts, even though a few misconceptions persist. However, there is no correlation between the richness of a concept map drawn by a student and her/his performance on the related exam.

The data indicate that the physics student teachers that were taught via traditional methods have a limited understanding of the quantum concepts related to the properties of the matter wave. Use of concept maps, semantic networks and computer simulations resulted in an increased knowledge of the content for all participating students. The same could be true of other quantum phenomena, which are significant in physics teaching, that students encounter; one is the nature of matter waves, which can be too abstract for the students. In addition, some students also have a significant misunderstanding about the processes of the transition and reflection of the matter wave from a potential step. This shows a lack in the students' understanding of their own experiences and observations. Therefore, in the teaching-learning environment, we need to provide students with the skills to interpret and express their own knowledge. To do so, it is necessary to devise strategies that provide students with the means to express their views with analogies, concept maps and semantic networks.

Though simulation can never replace practical experiments in science education, it does offer some distinct advantages. It allows learners to control complex systems, manipulate variables, run experiments, take measurements, etc., in ways which would be difficult or impossible to achieve with real world systems. In addition, simulations could turn some abstract concepts and relationships into objects and phenomena that can be manipulated and thus make them easier to understand (Li, Borne & O'Shea, 1996). Teachers may encourage meaningful learning by using tasks that actively engage the learner in searching for relationships between her/his existing knowledge and new knowledge; and by using assessment strategies that reward meaningful learning. According to Novak (2003), it is not possible for a learner to reach high levels of meaningful learning until some prior relevant knowledge structures are built. Thus learning must be an iterative process over time in order to build expertise in any domain of knowledge.

It is important to note that simulations strengthen the power of the conceptual map when inserted as a meaningful component in the learning process, and are tools that deepen the conceptual items of the map.

Moreover, in the teaching-learning process we observe that if students consult their concept maps and semantic networks while listening to a lecture, their comprehension of interrelations and links between concepts is facilitated. Similar observations have been stated by Goodwin & Orlik (2000).

Technology offers teachers and students enhanced opportunities to engage in scientific inquiry, as well as a multitude of ways to represent scientific concepts. Science educators should explore ways in which new technologies could be utilized to improve access to science instruction for students with visual impairments. Orlik (1988) reported that visual aids increase the perception of knowledge, consolidation of material, and quality of knowledge. Other useful types of schemas are concept maps. The results obtained from data show that concept maps and semantic networks also have a positive effect on student comprehension.

Quantum objects behave quite differently from classical objects. As the above studies indicate, the students mostly have a naive common sense way of viewing nature. As may be assumed for physics students they, for the most part, had difficulties with the giving up of determinants, especially concerning fixed values for the properties of objects. Any change related to the concepts which are held needs the students' willingness and cannot be forced, because it's at least partly a question of a point of view and thus a private matter. The main objective of such a course, therefore, should be to provide a solid physical foundation for the discussion of these and related items in order to allow for decisions about what can be sustained and what has to be abandoned due to well-justified (mathematical or physical) reasons.

The previous studies provide us with information about the relative difficulty in helping students learn abstract concepts through hands-on activities and computer visualizations (Thornton & Sokoloff, 1998; Rebello & Zollman, 1999). The study illustrates the concepts which students find most difficult at a conceptual level and shows how their attempts to understand both the conceptual and mathematical aspects of quantum physics may be induced to yield improved results.

Therefore, the attempt should be made to produce semantic networks, concept maps and computer simulations, and other teaching strategies which are more suitable for reducing the ratios of misconception for these concepts.

Consequently, technology offers teachers and students enhanced opportunities to engage in scientific inquiry, as well as a multitude of ways to represent scientific concepts. Curriculum developers, teachers, teacher educators and instruction technologists should work together with researchers to design teaching materials that help students develop skills in conducting the scientific process and to learn how to use them to make connections between life and school experiences.

CONCLUSIONS

The study showed that physics students often fail to comprehend fundamental concepts of quantum physics in the traditional teaching environment.

Firstly, the application of instructional materials, such as concept maps, semantic networks, and computer simulations used in physics education are effective in constructing new concepts that the students face. Moreover, these instructional materials are useful in increasing student achievement. As is appreciated, quantum physics requires advanced thinking in physics. Therefore, fundamental knowledge about calculus, functions, wave, etc. are important to improve understanding of the quantum physics concepts required. To that end, in order to reduce misconception ratios in quantum physics, the causes of misconceptions should be determined and clarified. These are often due to the lack of fundamental knowledge and/or to corresponding teaching strategies. Hence this researcher concludes that it would be more reasonable to approach this issue after these determinations are done in detail.

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