An instructional design model to teach nature of science

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Abstract

The "explicit-reflective-embedded" approach is an effective way of teaching nature of science (NOS). But, the studies have not provided a clear or explicit definition of the approach in terms of an instructional design framework. The approach has two sides including embedding into content knowledge and purposively teaching the NOS aspects as a cognitive variable. The purpose of this study is to adapt an instructional design model for teaching NOS in the context of university level biology courses. In this study, four-round Delphi study approach was utilized. The results of Dephi study has shown that six experts have critisized requirement of too much time and effort in implementation, have warned about probable problems for novice implementers and lack parts in the design process as the negative opinions while giving systematic frame to teach scientific literacy aspects and appropriateness for biology courses have been provided as the positive opinions. After the corrections on the critics of the experts, adaptation of instructional design model was completed. The model might provide an instructional guide for NOS teaching in universities.

Keywords: nature of science, instructional design model, biology courses, explicit-reflective-embedded approach

Introduction

Nature of science (NOS) has been thought of as an important requirement for the informed-decision making and being active citizen in a society. These qualities, in relations to daily life, have been discussed in science education literature on scientific literacy (Uno & Bybee, 1994; Damastes& Wandersee, 1992). As a component of scientific literacy, NOS has been emphasized as an important aim in the science education research literature and certain international examination frameworks such as PISA and international reform documents (Damastes& Wandersee, 1992; Klymkowsky, Garwin-Doxas & Zeilik, 2003; OECD, 2003; BSCS, 1993). NOS is defined as "the values and assumptions inherent to science, scientific knowledge, and/or the development of scientific knowledge" (Lederman, 1992;331). NOS has included some aspects from scientific method to science in society. Epistemological and educational studies have resulted in a purified set of aspects to teach NOS in schools (McComas, 1998). Aspects of NOS include the fact that scientific knowledge is based on evidence and observation, but scientific knowledge is also tentative. A scientist is not objective when he or she begins to study; he or she has a background embedded in social and cultural context. In line with these explanations, creativeness and imagination are also important in producing scientific knowledge. In its basic meaning, science is a way of knowing and does not have a universally accepted right way. Another aspect of science is that there is no hierarchy among theory and law; they each have different roles in science (McComas, 1998, Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002).

Science education researchers and reformers have struggled to teach NOS, and studies have shown existence of many misunderstandings of the NOS aspects. These misunderstandings have been presented by various groups including teachers, pre-service teachers, teacher educators, students and textbooks (McComas, 2003; Akerson, Morrison & Mc Duffie, 2006; Abd-El-Khalick, Waters & Le, 2008; Blanco & Niaz, 1997; Tsai, 2006; Irez, 2006; Ryan & Aikenhead, 1992). The most important and relevant context to learn about the NOS aspects is through science courses. Teaching approaches and materials in science courses are basic means to learn about NOS. Many science lessons, textbooks and subjects begin with NOS issues and continue with content knowledge. Biology teaching textbooks, in particular, start with NOS issues and continue with content knowledge. In spite of this emphasis and priority, the literature has continuously shown misunderstandings of pre-service biology teachers and biology teachers about NOS (Nehm & Schonfeld, 2007). Nehm and Schonfeld (2007) studied forty-four secondary level biology teachers, and they found the participants commonly believed that theories become facts when well supported, and a theory is a weak scientific idea. In addition, Chiapetta and Fillman (2007) and Irez (2008) have shown existence of unacceptable ideas and descriptions in biology textbooks. Biology is an important area for people's informed-decision making on a daily basis. Socio-scientific issues such as genetically modified products, cloning, global warming and ozone depletion are active biology research topics. At the same time, biology is addressing important subjects including evolution to teach NOS. The problems of learning NOS in biology education contexts have required instructional solutions to teach NOS at the teacher education level.

In science education literature, there are three instructional approaches that are not framed in a systematic instructional design model to help teach NOS. These approaches are the historical approach, implicit approach and the explicit-reflective-embedded approach (Khishfe & Abd-El-Khalick, 2002; Meichtry, 1992; Palmquist & Finley, 1997; Palmquist & Finley, 1998; Lin & Chen, 2002). The explicit-reflective-embedded approach has been actively studied and shown to be effective on NOS teaching in pre-service and in-service teacher education programs (Akerson, Abd-El-Khalick & Lederman, 2000; Küçük, 2008; Akerson & Volrich, 2006). The explicit-reflective-embedded teaching requires deliberate planning, assessment and explanations (Akerson & Volrich, 2006; Lederman, 2007). This requirement needs preparation prior to instruction in order to teach NOS. In the literature, instruction is defined as "intentional (explicit) facilitation of learning toward identified learning goals" (Smith & Ragan, 2005, 4). Instructional design is defined as "the systematic and reflective process of translating principles of learning and instruction into plans for instructional materials, activities, information resources and evaluation" (Smith & Ragan, 2005, 4). By taking the systematic and intentional nature of instructional design approach into consideration in line with components of the explicit-reflective-embedded teaching, NOS teaching might be more effective.

At the same time, as stated by Dick, Carey and Carey (2005), as a new understanding of learning and instruction becomes accepted, the existing instructional design models should be refined and enhanced to meet required developments. For example, the multiple intelligences approach has been incorporated into the Dick and Carey Model for refinement of existent instructional approaches on multiple intelligences and for providing a more comprehensive model of instructional design for multiple intelligences based applications (Tracey & Richey, 2007). Need for embedding NOS into biology content as a new point to consider in biology teaching should also be seen to change existent models. Accordingly, clearer and more comprehensive guidelines for NOS teaching is needed to overcome problems regarding to NOS learning in biology courses.

Purpose of the study

In this study, the explicit-reflective-embedded approach is used as a core idea for adapting an instructional design model for NOS teaching in biology courses at the university level. The model is, subsequently, validated by a group of experts.

Method

For adapting the model, the literature review on the explicit-reflective-embedded approach, and other approaches used in NOS teaching, was conducted first. Then, the framework of an instructional design model was determined by investigating the related literature. The important components of these varied approaches to teaching NOS were incorporated into the framework. Next, the model was personally validated by asking science education experts about utility, adaptability, feasibility and understandability of the components of the model (Wedman & Tesmer, 1993; Dick, Carey & Carey, 2005). Finally, a four-round Delphi Study approach with a panel of six experts was utilized to provide evidence of internal validity of the model. The characteristics of the experts are presented in Table 1.

Expert Code	Posession of Master or PhD Degree	Department	Research Interest	Experience on Education (Year)
E1	PhD	Science Education	Instructional strategies, measurement and evaluation	14
E2	PhD	Secondary Science and Mathematics Education	Instructional strategies, technology supported education	8
E3	PhD	Program Development and Instruction	Self-regulation and goal setting	7
E4	MEd	Elementary Teacher Education	Scientific Literacy	3
E5	MEd	Computer Technologies and Instruction	ARCS model, motivation	3
E6	MEd	Elementary Teacher Education	Program development, material design and instruction	5

Table 1. *The basic characteristics of the experts*

In the first round, the proposed model was introduced to the experts with its theoretical foundations. Then, the application of the open-ended questionnaire about the different aspects of the model was discussed in the second round. The questionnaire items were related to utility, adaptability, feasibility and understandability. The items were designed to provide negative and positive opinions on the model. Therefore, each item included two sub-items. For example, one question asked, "Could you evaluate the model in terms of utility?". The following sub-questions were, "Could you provide negative aspects of the model in terms of utility?" and "Could you provide positive aspects of the model in terms of utility?". After this analysis, the experts were asked, "What is the best important characteristic of the model for you?". Finally, the revised model was presented to the experts to provide consensus.

Proposed instructional design model for teaching NOS

The results of the literature review on instructional design models provided important points while selecting appropriate initial instructional framework (Isman et al., 2005; Dick, Carey & Carey, 2005; Morrisson, Kemp & Ross, 2004; Keller, 1987; Schunk, 2004; Wongwiwatthananukit & Popowich, 2000). The instructional design model presented here is based on Dick and Carey's (2004) model including assessment, design, development, implementation and evaluation (ADDIE). The model has focused on instruction from a systematic approach in which all of the instructional factors including evaluation, objectives, students, etc. are considered as components of the same system and they impact each other. In addition, the Dick and Carey Model provides standardization of the instruction in a task specific manner and takes into account behaviorist, cognitivist and constructivist approaches (Dick, Carey & Carey, 2005). The model describes instruction as a systematic process including balancing all components such as the teacher, materials, students and learning environment to provide successful learning. In the model, a system is defined as set of interrelated parts working together to reach a defined goal, and the whole system uses feedback to determine whether the desired goal has been reached (Dick, Carey & Carey, 2005).

In the literature, an example of successful integration of the Dick and Carey Model in biology learning context have been provided (Bozdin & Park, 1999). A requirement of deliberate or explicit control of all components of a system of instruction gives the model an important place in teaching NOS and biology content knowledge in the same system. The Dick and Carey Model has provided an important systematic model to consider both NOS aspects and biology content knowledge. In NOS teaching, since both content and NOS aspects should be taught together, there is a need to consider two separate focuses in spite of their embedded relationship. Therefore, NOS teaching is different than basic content teaching processes in terms of instructional design. The Dick and Carey model has flexibility to adapt to nature of science teaching purposes. The Dick and Carey model can be seen in the figure 1.

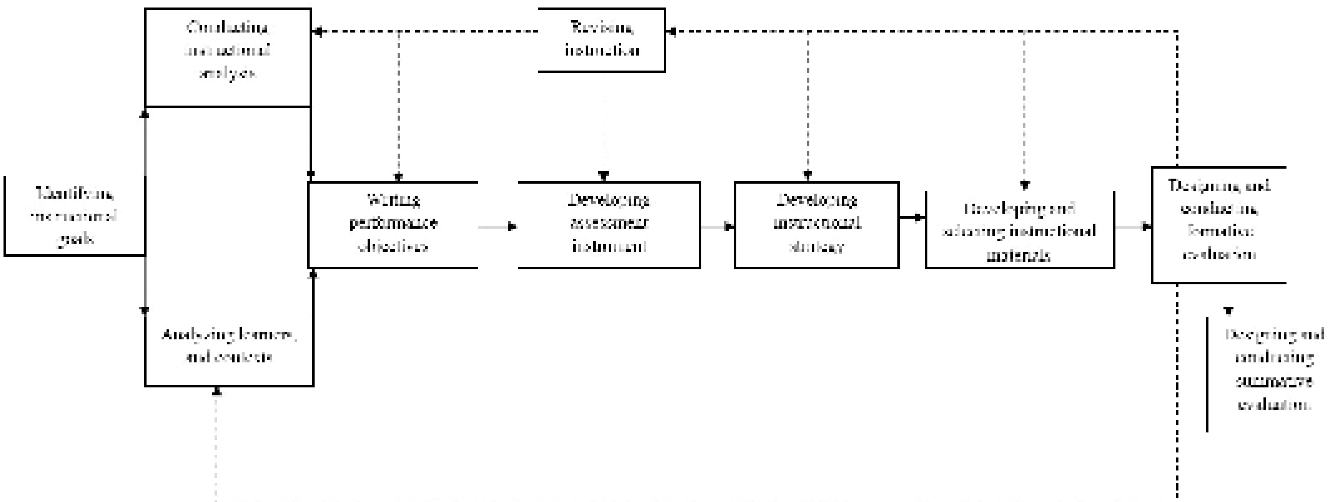

Figure 1. *The Dick and Carey systematic instructional design model (Dick, Carey & Carey, 2005)*

As seen in the model, there is an iterative process to develop instruction, and the components of the model are interrelated and have equal importance for reaching instructional goals. Using the Dick and Carey Model as a framework, the following instructional design model for NOS teaching in a biology unit was constructed by considering explicitness, reflection, embedding and two knowledge types.

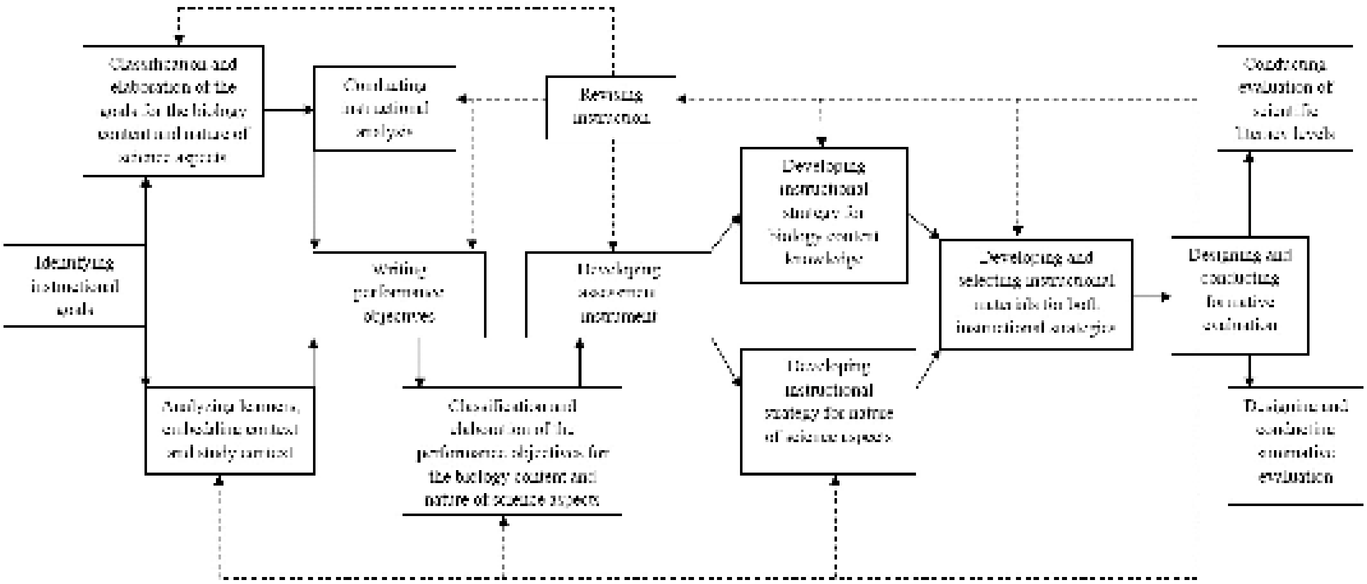

Figure 2. *The proposed instructional design model for the nature of science teaching (NOS instructional design model)*

The first component, identifying instructional goals includes expectations about outcomes after instruction. In the Dick and Carey model, assessment is necessary for performance analysis, students' learning experiences during the unit and analysis of students when they first learn about the unit. In addition, requirements of the new instruction should be considered by investigation the assessment results to set goals for the instruction (Dick, Carey & Carey, 2005). Pre-determined curricular arrangements drive goals set in school environments. The proposed model requires three important points in goal setting procedure. When creating goals, they should be based on both biology content knowledge and NOS knowledge under the scientific literacy construct. Secondly, "the classification and elaboration of the goals for the content and the NOS aspects" phase emphasizes explicit intention to teach NOS as an important instructional goal while teaching biology content knowledge. To provide such a distinction, instructors should classify the goals as biology content knowledge goals and NOS teaching goals. Then, there is a need to provide common instruction between biology content knowledge and the NOS aspects. In this situation, the purpose is to balance any pre-dominancy of the instructional content by elaborating on the goals of balanced instruction. The other two phases, which require the analyses on entry components of the instruction, are analyzing learners, embedding context and study context and conducting instructional analysis. The phase of conducting instructional analysis has sought an answer to the question of "what entry behaviors including skills, attitudes and knowledge are required of student to begin the instruction?" while the phase of analyzing learners, embedding context and study context has tried to answer the question of "how are the instructional setting, embedding context for desired NOS aspects and learners' current understandings of both the biology content and NOS?". After the pre-analysis of the learner, contexts and pre-requisite entry behaviors for the instruction, specific statements about biology content knowledge and NOS can be written based on the results of analyses. The phase of writing performance objectives is a synthesis phase to set objectives using the evidence provided by previous analyses. Similarly to the classification and elaboration of the goals for the content and the NOS aspects phase, the instructor should classify the specific objectives on both NOS and biology content and should elaborate on them to provide balanced instruction for both subjects in the phase of classification and elaboration of the performance objectives for the content and NOS aspects. In the next phase, developing assessment instruments, is based on the objectives determined in the previous phase of the design. In this phase, there is a need to develop ,at least, three assessment instruments for biology content, NOS content and scientific literacy. Then, two parallel phases of instructional strategy development surface. These are developing instructional strategy for biology content and developing instructional strategy for the NOS aspects. In these phases, the components that facilitate learning biology content and NOS are emphasized. In line with this purpose, pre-instructional activities, explicitly presentation of the content of NOS or presentation of biology content, embedded strategy (determining order of the contents and the part of biology content in which NOS aspects will be embedded), determination of mode of learner participation (group or individual), assessment and other related activities are prepared by considering learning theories and educational research findings. In the following phase, developing and selecting instructional materials for both instructional strategies, the instructor should decide on instructional materials by taking into account type of learning outcome (cognitive, affective or psycho-motor), availability of relevant materials, content differences of instructional process (NOS and biology content knowledge). In addition, the criteria for selection of materials should be determined. The phase of designing and conducting formative evaluation has provided feedback for the improvement of instruction and the instructor will have received different types of information about instruction for future. The Dick and Carey model has been suggesting three types of formative evaluation: one-to-one evaluation, small-group evaluation and field-trial evaluation (Dick, Carey & Carey, 2005). Based on the data coming from formative evaluation, the phase of revising instruction is conducted to improve efficacy of instruction. Revising activity is directly related to all components of the system and is key to coherence between the components. The other evaluation attempt in the model is designing and conducting summative evaluation. Dick, Carey and Carey (2005) regarded this evaluation phase as a separate evaluation that is not a part of the instructional design process. The summative evaluation has required an independent evaluator. The final phase of conducting evaluation of scientific literacy levels, is an important part for NOS instruction, since informed decision making and becoming an empowered citizen are indicators of scientific literacy. Scientific literacy includes knowledge about NOS as a component to gain these abilities (Uno & Bybee, 1994; Damastes& Wandersee, 1992). Therefore, evaluation of scientific literacy should be an important part in any instructional attempt to teach NOS. A panel of experts provided their opinions according to the proposed model.

Results

All of the experts have stated that the model might be used to teach NOS and the model has a potential for teaching NOS in biology courses at the level of university although they have critisized some aspects of the model. Their evaluation will be presented in the following sections.

Utility of the model

The experts have stated that time and effort requirements of the model should be thought when using the model for instructional purposes. For example, based on the question for utility aspect, E2 has pointed out that, “preparing instructional materials for different contents might not be an easy task every time with the load of developing appropriate strategies”. Then, E1 (Expert 1) has added that, “novice implementers might experience restrictions for the frequent feedback process and correction, and the time might also be another restrictive factor”. With a different focus, E3 has explained that the model might be appropriate only for the faculties of education. The expert has given reason for this by stating that, “the model is appropriate for education faculties of universities, since implementers should be knowledgeable about instructional design”. E6 has extended the criticism by stating that, “every instructional design process seems as like only ‘a schema on a paper’ without applying it; negative and positive sides of the design can not be seen without application and expense analysis". In spite of these negative opinions, the experts have also provided positive opinions on the utility aspect of the model. E1 has stated that "the model has been providing a systematic approach to biology teaching and detailed design of the steps and process in addition to frequent control-feedback system that might prevent probable problems before the instruction. The model is also providing appropriate order of actions to be implemented in teaching". E2 has emphasized the different aspect of the model by writing that, "[the model] is providing a way to reach the goals on scientific literacy in a planned manner. Separate considerations of the biology content and NOS will increase the utility of the model in terms of teaching on these subjects". E4 has stated that the model can easily be used at the university level. E5 has also added that the model might provide integration between content, instruction and learner. Additionally, selection of the systematic model increases the utility. E6 approves that "*the model has been reflecting the basic components of a model based on systematic instructional design*". So, utility of the model for biology courses have also been supported by the experts.

Adaptability of the model

For the adaptability aspect, E3 has pointed out, without providing any negative opinion that, "the model is constructed with a general model approach so it might be adapted into other courses," while E4 stated that adaptation of the model requires care and experience. E6 suggested that the model might include a part for adaptation into other science courses, by providing such a part at the planning phase, the adaptability of the model might be increased. In contrast to these opinions, E1 has stated that, "*the model is hard to adapt it into the other courses in which content are not as homogenic as biology course content*". E-2 explained as a different aspect that, "the novice implementers might not have appropriate adaptation skills". Also, E5 has stated that, "*if we consider the adaptation of human being into new process, it might be a problem for adapting the model that implementers should pay more time and effort*".

Feasibility of the model

On the feasibility aspect of the model, E1 has criticized the model, saying that "*the implementers might develop resistance to use the model in common traditional* *approach dominated contexts*". E2 has emphasized the implementer's characteristics in consideration with the feasibility saying that, "*the activity and strategy development parts have been requiring a certain knowledge base and skills*" whereas the expert has written that "*such an approach [the model] is feasible at the level of university but not in elementary level*". E1 has also added that, "*the model is feasible for the instruction provided in university or higher levels*". Similarly, E4 has seen the model as feasible to use in university level courses. E5 has noted that, "*the implementers in university level might use such a model in a shorter time than any other group of implementers since they have more experience and knowledge about it [instructional design model]*". E6 thought the model is feasible for undergraduate biology courses in science teacher education programs.

Understandability of the model

For the last aspect; understandability, E2 commented that, "*the implementer might not understand how to organize all of the components of the model,*" while E1 suggested to add some components for increasing "*understandability*" that "*the appropriate examples and explanations should be provided for each step in addition to the figure*". E1 has positively stated that, "*individuals who experience teaching-learning process might easily understand the model, especially; researchers in education will use the model more effectively*." E4 has emphasized requirement of a guide to understand the model due to different lines and arrivals in the model. E5 has also stated a need to explain the model in a linear approach to increase understandability of the model. Similarly, E6 explained a need to provide a guide or map to increase understandability of the model.

Apart from all of these opinions, E3 provided detailed analysis of the model in terms of the instructional design process. The expert has emphasized requirement for a "*reflective evaluation*" phase and follow-up "implementation" phase. The reflective evaluation phase is requirement for assessing the phases before the implementation to change appropriate parts. Again, the model needs to have an implementation phase before the formative evaluation, which is based on application in implementation. The other two factors recommended by E3 are, "*determination and integration of the contents for both biology and NOS*" and "*integration of the strategies for biology content and NOS*" phases. These two phases are very important for explicitly embedding or integration of biology content and the NOS aspects due to their planned nature to approach on both of the contents together.

As a result of the third round, the experts have stated the most important factors to consider in the model. Their answers have shown that "*use by novice implementers*," "*requirement for a guide*," "*lack of reflective evaluation*," "*too much time and effort consumption*" and "*complexity of the model to understand*" have been regarded as most important factors to implement the model in biology courses .

During the final round, experts were asked about the revised model. E6 wanted to add "*expense analysis*" into the model. After that, consensus on the final form of the model was provided.

Conclusion and implications

The experts suggested that the model demands some attention in regards to the requirement of time and effort consumption on the components and differences between novices and experts using the model. This might be the reason for ineffectiveness of the model in terms of utility, adaptability and feasibility. This point needs attention during impolementation phase. In fact, time and effort factors should be analyzed in detail after the implementation of the design model in biology courses; but novice and expert differences might not be so effective, since the model was proposed for education faculties in which members are familiar with the instructional design terms and approaches. As a support, the experts have also stated the appropriateness of the model at the university level. For the understandability aspect, the negative opinions focused on the lack of examples and explanations. As a solution to this problem, the requirements of each step have been explained in this paper under the section of Proposed Instructional Design Model for Teaching NOS. Despite all of these criticisms, as stated by E2, the model has provided an important framework for reaching goals related to scientific literacy in the context of biology courses. After all of the revisions from the critics, the final model was constructed (see Figure 3).

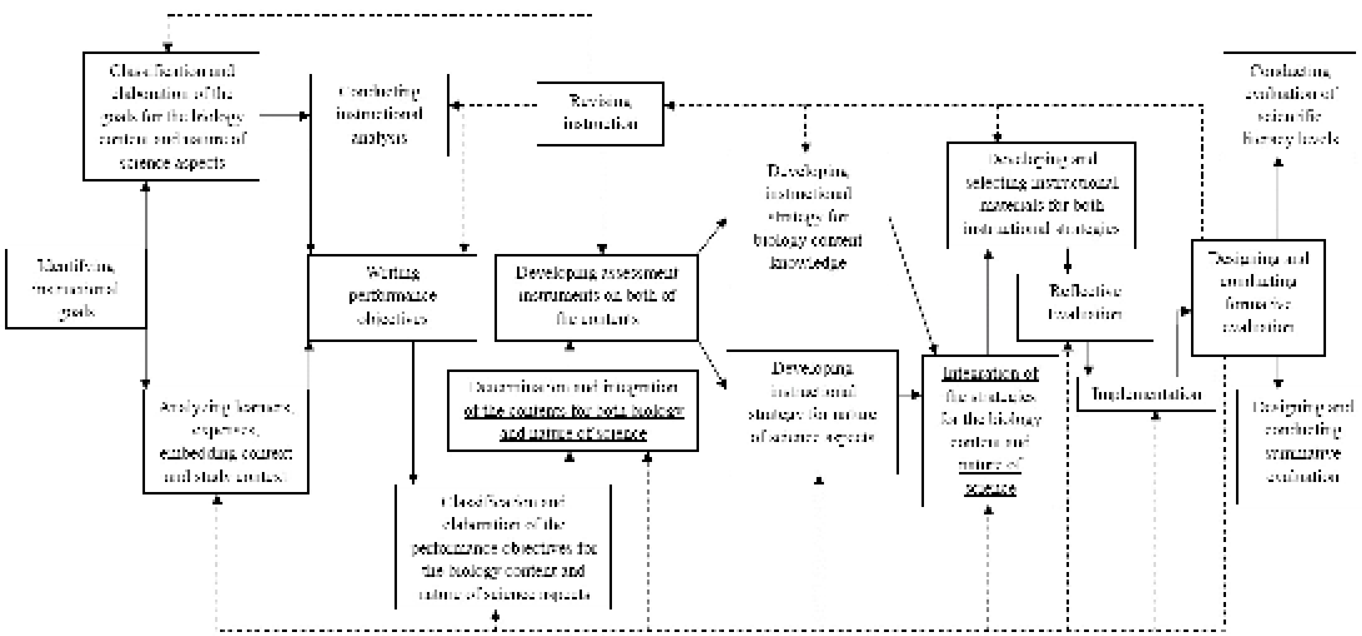

Figure 3. *The revised final instructional design model for the nature of science teaching (NOS instructional design model)*

Researchers writing about benefits of instructional design have been suggesting that the instructional design process increases the probability of goal attainment and fosters positive attitude and motivation, although there is no best way to design an instructional material (Morrison, Ross and Kemp, 2001). Dick, Carey and Carey (2005) have extended the benefits of the instructional design process by stating that systematic approach to instruction design provides an empirical and replicable process. As an empirical evidence, a study using the Dick and Carey Model has shown effectiveness of the model in biology learning contexts including environmental issues learning tasks (Bozdin &Park, 1999). The more comprehensive list of benefits of instructional design have been provided by Smith and Ragan (2005). The authors have written that a systematic instructional design encourages advocacy of learner, supports efficient, effective and appealing instruction, facilitates congruence among objectives, activities and assessment and provides intentional, systematic and certain framework for dealing with learning problems (Smith & Ragan, 2005). In addition to these general benefits of the instructional design process, it provides the contribution to see the separate components of instructional design models for NOS teaching in the same system. The literature of NOS teaching has shown a need for an explicit, intentional and systematic attention to teach NOS. The “explicit-embedded-reflective” approach has been shown to be an effective way for overcoming problems regarding misunderstandings of NOS (Khishfe & Lederman, 2007; Khishfe & Lederman, 2006). The systematic instructional model provides explicit and intentional attention which is requirement of the explicit-embedded-reflective approach. At the same time, the model has given a systematic framework for constructing a link between the components of the explicit-embedded-reflective approach beginning from planning, selection of activities and embedding strategy, conducting assessment and reflecting on the previous ideas and process to revising the approach.

In the literature, there is another example of developing and validating an instructional design approach by using a similar approach to the one used in this study. Tracey and Richey (2007) have incorporated the multiple intelligences approach into the Dick and Carey Model for instructional design. The authors have studied with four experts by using Delphi Study approach in three-round period. They have provided a validated and refined model by using two different theoretical lines as learning and instructional design.

In conclusion, the model might be an alternative for development of NOS teaching in university biology courses in the faculties of education. The proposed model in this study is a starting point to discuss the effectiveness of the model, so there is a need to implement the model in the real context. At the same time, there is a need to address critics in terms of theoretical appropriateness of the model for teaching NOS. In these courses, the existence of two sides of instruction as content and NOS knowledge needs further elaboration for balance and embedded strategies.

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