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Report on main obstacles to implementing inquiry and intervention programmes in IBSE

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A. Background to this report

This report is a deliverable of Work Package 4 (WP4) of the European FP7-funded project "European Science and Technology in Action: Building Links with Industry, Schools and Home" (ESTABLISH; 244749, 2010-2013). It meets the requirements of the Deliverable 4.1 by presenting a report on the main obstacles to implementing inquiry and intervention programmes developed to tackle as presented by the beneficiaries of ESTABLISH. (See Table 1 below for beneficiary list).

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B. The ESTABLISH consortium

Beneficiary short name	Beneficiary name	Country	Abbreviation
DCU	DUBLIN CITY UNIVERSITY	Ireland	IE
AGES	AG EDUCATION SERVICES	Ireland	IE
UCY	UNIVERSITY OF CYPRUS	Cyprus	CY
UmU	UMEA UNIVERSITET	Sweden	SE
JU	UNIWERSYTET JAGIELLONSKI	Poland	PL
CUNI	UNIVERZITA KARLOVA V PRAZE	Czech Republic	CZ
AL	ACROSSLIMITS LIMITED	Malta	MT
UPJS	UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH	Slovakia	SK
COUO	CARL VON OSSIETZKY UNIVERSITAET OLDENBURG	Germany	DE
UTARTU	TARTU ULIKOOL	Estonia	EE
UNIPA	UNIVERSITA DEGLI STUDI DI PALERMO	Italy	IT
MaH	MALMÖ UNIVERSITY	Sweden	SE
IPN	LEIBNIZ-INSTITUT FUER DIE PAEDAGOGIK DER NATURWISSENSCHAFTEN UND MATHEMATIK AN DER UNIVERSITAT KIEL	Germany	DE
CMA	CENTRE FOR MICROCOMPUTER APPLICATIONS	Netherlands	NL
MLU	MARTIN LUTHER UNIVERSITAET HALLE-WITTENBERG	Germany	DE

Table of Contents

1. Introduction

This report summarises discussions from the ESTABLISH consortium and the key reports from literature on the challenges and obstacles that teachers have identified as potential barriers to the implementation of IBSE. By identifying these potential obstacles and challenges, action can then be directly taken within the ESTABLISH teacher education workshops to address these issues and concerns.

A discussion on a review of published literature to determine how interventions and programmes have been conducted with both novice and expert teachers to introduce and encourage teachers to adopt inquiry based approaches in their teaching. The results from this report will be used to inform the development of the IBSE teacher education workshops as part of the ESTABLISH project.

2. Challenges teachers face in implementing inquiry

This section reports the challenges that that teachers face in implementing inquiry based teaching practices in their classrooms. During the General Assembly meeting of the ESTABLISH consortium in Dublin (September 2010), a discussion on what barriers can hinder teachers from adopting inquiry-based teaching was conducted. The barriers identified during these discussions are summarized in Table 1.

Table 1. Examples of barriers in using inquiry-based teaching in schools

Barriers to using IBSE	**Examples**
Teacher beliefs	Understanding scientific inquiry Beliefs about efficient learning Beliefs about content knowledge Teacher scientific knowledge Awareness of knowledge limits Efficient learning is not the same as IBSE Pedagogical Content Knowledge (PCK) Experience of prior learning Student capabilities Attitudes towards IBSE versus Science Learning environment richer Teacher – questioning environment Teacher confidence "Culture of change" – school - teacher
Classroom management	Move from teacher centred to student centred approach Classroom control Lack of effective material Lack of time Core curriculum More time for preparation (for teachers) Involvement of IBSE materials
Pedagogical and scientific knowledge	Develop students' questioning skills Encourage curiosity and creativity Fair testing Argumentation Evaluate evidence What and how to assess IBSE, formative/summative

After this discussion a review of the literature about the challenges that teachers face in implementing inquiry based teaching practices in their classrooms has been carried out. The challenges reported in the literature are presented under the headings of *Teachers beliefs, Management* and *Pedagogical and scientific knowledge.* The order given does not reflect any hierarchy of importance. The literature reference is included for ease of reference to the original study.

2.1 Teacher beliefs

The struggle both in-service and pre-service teachers can have in applying an inquiry methodology can stem from deep-set personal beliefs and historical events within their own education. Teachers' role identities are influenced strongly by their own individual experience of past teachers as well as the strength of their own teaching beliefs. An individual is shaped by the experiences they encounter throughout their life, and in that sense, previous experiences with education and positive or negative teacher role models can shape this individual as a teacher themselves. Having strong beliefs about teaching, based on reflection of these past experiences, can also lead to a stronger role as a teacher in the classroom (Eick & Reed, 2002). Lee and Witz (2008), found teachers were doing what they thought was important to students, and that their teaching was based on their own values, philosophies, personal concerns and experience – suggesting that curriculum reforms do not effectively connect with teachers' deeper values. Also Moore, Edwards, Halpin and George (2002) report that teachers tend to incorporate new policy into a largely unaltered practice.

Teachers may fail to understand fully the concept of inquiry for many reasons. Many teachers have received little or no scientific research experience in their own education which may contribute to the lack of their scientific content knowledge (Zion et al., 2007). Also teachers' lack of Knowledge on the Nature of Science can be a barrier to implementing IBSE-teaching (Roehrig & Luft, 2004; Lederman, 1999; Abd-El-Khalick et al., 2001). Most teachers have inadequate ideas *about* science and there is a complex relationship between teachers' stated beliefs about science and how they actually present science in their classrooms (Abd-El-Khalic & Lederman, 2000). Studies show that many teachers teach the scientific content in preference to the nature of science (Sadler, Amirshokoohi, Kazempour & Allspaw, 2006).

Teachers' beliefs about how students learn and what is important to teach them affect how they teach. According to Anderson (2007) there are four elements of learning that are crucial in inquiry. Learning is an active process. This means that how individuals construct knowledge is dependent upon the individuals' prior conceptions. The understanding that each individual constructs is dependent on the context. The more abundant and varied contexts the richer understandings are acquired. Finally meanings are socially constructed. Therefore understanding is enhanced by sharing and discussing ideas with others. Many teachers believe that it is important to prepare the students for the next level of education and these teachers fear that this preparation will suffer if they devote time to inquiry activities. Another tension that exists is to teach science to suit all students and also provide a strong education for the more-able students (Anderson, 2007).

2.2 Classroom Management

Many teachers find it difficult to allow a student centred approach to unfold in their classrooms (King et al., 2008) and teachers can feel incapable of managing classrooms when using an inquiry approach. Within an inquiry classroom, students may be doing different activities and also the noise level may be higher than in a 'traditional' classroom as group discussions may be taking place. (Baker et al., 2002; Basista & Matthews, 2002).

The concerns over time constraints can be related to the need to adhere to the curriculum. Practicing teachers may believe that teaching by inquiry takes more time than more traditional teaching and may feel under pressure to cover the curriculum content prescribed for the school year. (Lehman et al., 2006; Buczynski & Hansen, 2010; Loughran, 1994, Anderson, 20007). Teachers experience the tension between educational arguments for devoting time to developing students' understanding of scientific processes and the reality in the classroom. (Bartholomew, Osborne & Ratcliffe, 2004).

2.3 Lack of Pedagogical and Scientific Content Knowledge

Teachers may fail to understand fully the concept of inquiry and particularly how to implement it effectively in the classroom (Enochs et al., 2000; Crawford, 2000; Roehrig & Gillian, 2004). Also, teachers with a lack of scientific content knowledge may be more inclined to steer investigations towards topics they are comfortable with. This practise can lead to low self efficacy and a move towards more the more traditional approaches that they are familiar with. (Garet et al., 2001; Enochs et al., 2000; Basista & Matthews, 2002).

Teachers are uncomfortable with not knowing all the answers that arise during inquiry investigations and tend to steer students toward questions which the teachers knows the answers to or investigations that they know what to expect the outcome will be. Some teachers deliberately made use of "safe questions" so that the students have some faith in their knowledge as a teacher and that the students themselves can begin to feel some level of progress in knowing the correct answer (Zion et al., 2007; Enochs et al., 2000; Ramey-Gassert et al., 1996).

Unexpected results from experiments or research literature can lead to changes in the overall topic investigation. Teachers must be able to cope with such changes and continually encourage students to delve deeper into solving the problem. This can be seen as a negative aspect to some teachers as they find it harder to control the direction of the topic or investigation when this occurs. Mistakes and unexpected results are part of the inquiry process and they can allow students to examine new ways to overcoming obstacles and lead to a deeper understanding of the topic in question. Teachers must encourage students to develop and refine investigative questions, plan valid investigations that bear in mind the appropriate variables, and to interpret evidence as it arises (Zion et al., 2007; Lehman et al., 2006).

One problem faced by many teachers of inquiry is in making a relationship between concepts and real life situations in order to engage students and show them how the concepts are relevant to their daily lives. Teachers must also use contexts to show how concepts can be related across the curriculum (King et al., 2008). Newton, Driver and Osborne (1999) report that teachers often do not have faith in their own ability to teach when the students engage in argumentation. Teachers also feel insecure about to what extent they should be involved themselves in the classroom discussions and to handle the anxiety or emotions caused by, for example, work in gene technology (Bryce & Gray, 2004). Often the problem does not seem to be the content itself, but rather in teaching ideas about science and conducting teaching which includes argumentation (Gray & Bryce, 2006).

Processes common to inquiry based teaching approaches are: encouraging students to raise questions; guiding students in the search for information and in critical examination of information and in the process of planning and evaluating inquiry; scaffolding argumentation. Research has shown the limited strategies teachers that have for helping students to structure information-seeking in inquiry. In a review of teaching of science inquiry, Osborne and Dillon (2010) report that even when teachers hold clear and coherent views about the nature of science they do not teach inquiry using those views in any consistent manner. Rather, they concentrate on the immediate concerns of classroom management and on concept acquisition and development. Developing a discourse for teaching inquiry is needed for teachers to address issues of planning, questioning and evaluating.

Even in the UK, where inquiry has been established for over twenty years, studies show that such discourse is limited (Millar, 2010).

Mitchener and Anderson (1989) defined five concerns for teachers working with content that has humanistic perspectives on science. These concerns deal with elements that are included in inquiry based education as well. The teachers feel worried over reduced canonical science content, discomfort with small-group instructions, and uncertainties over student assessment, confusion of the teacher's role and frustration with the "non-academic' type of students attracted to the course.

Since the national assessments used largely test knowledge or recall of discrete science facts, concepts, and theories, teachers are constrained by the need for wider topic coverage. They often resort to using less demanding (both for them and students) teaching strategies, such as call-and-respond formative assessment, which focuses on factual level information, and verification labs rather than investigations that have some opportunities for student responsibility and decision-making integrated. Ironically, the findings from the research synthesis by Minner, Levy and Century (2009) indicate that teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than strategies that rely on more passive techniques.

2.4 Other important issues to consider

Anderson (2007) reports that there are some key factors that are important for inquiry to be successfully introduced. There is a need for good teaching material. Ideally the teachers can develop their own material but most teachers need to start with something that gives them support and new ideas. It is then important that teachers do not work alone but have colleagues to discuss materials with and whom can help each other to develop their teaching. The teachers also need support over time. (More on research on teachers' professional learning in science education in Bell & Gilbert, 1996 and Clarke & Hollingsworth, 2002). As Fullan has established, any change is dependent on the introduction of new materials, approaches and a challenge to existing beliefs (Fullan, 2001). Yet change requires more than teachers receiving well-written instructional materials (Hoban, 2002). Hoban identifies a combination of conditions for teacher learning that are needed for development to take place. These are a conception of teaching as a dynamic relationship with students and with other teachers where change involves uncertainty; room for reflection in order to understand the emerging patterns of change; a sense of purpose that fosters the desire to change; a community to share experiences; opportunities for action to test what works or does not work in their classrooms; conceptual inputs to extend teachers' knowledge and experience about the teaching inquiry); and finally sufficient time to adjust to the changes made. Most of all it takes time for change to occur. One example of this is discussed by Krajcik et al., (1994) which reports on a collaborative model for helping middle grade science teachers learn project-based instruction.

3. Intervention Programmes in IBSE; how to develop inquiry with teachers

This section presents some published literature on professional development programmes that have been developed for teachers in adopting inquiry approaches. It is not an exhaustive list of all intervention programmes in IBSE but it provides a useful overview of the range of these programmes in terms of workshop content and effectiveness.

3.1 Institute of Inquiry

The Institute for Inquiry (Exploratorium Insitute for Inquiry (2006)) has developed facilitator guides which detail how they run inquiry workshops for teachers at all levels. Under the title of "Fundamentals of Inquiry" a range of workshops can be conducted following the guides provided. The workshops presented under the subheading "Elements of Inquiry" include "Comparing Approaches to Hands on Science", "Process Skills" and "Raising Questions". The workshops "Stream Table Inquiry" and "Subtle Shifts: Adapting Activities for Inquiry" are classified under subheadings "Immersion in Inquiry" and "Connections to the Classroom" respectively.

In the first workshop, "Comparing Approaches to Hands on Science“ participants are exposed to different types of inquiry with three different stations set up where they carry out activities on spinning tops from the learners' point of view. Each station in the workshop refers to a different type of inquiry: Station A is heavily guided by a teacher/facilitator using a pre-prepared worksheet, Station B challenges participants to solve a given problem and Station C is an open activity that allows participants to investigate any aspect of spinning tops that they decide. (Exploratorium Insitute for Inquiry, 2006). This workshop acts in accordance with the National Science Education Standards which state, *"Teachers should use different strategies to develop the knowledge, understandings, and abilities described in the content standards. . . . Attaining the understandings and abilities described . . . cannot be achieved by any single teaching strategy or learning experience"* (NSES 1996 cited in Exploratorium Insitute for Inquiry, 2006). The guide describes how facilitators should focus participants attention on variables, explain differences in results or between experiments, encourage participants in their research, respond to positive and negative experimental outcomes by asking questions such as "Why this occurred?", "How could it be improved further?" etc. Facilitators should expect different responses and some frustration from participants. Questions should be actively encouraged while distractions should always be avoided. After each station of the workshop, participants are allowed to congregate into groups to discuss their results, possible solutions to problems and suggest further questions they wish to pursue. Fter completing the three stations the three methods of instruction are analysed and compared and teachers are facilitated to reflect on the workshop overall to establish a deeper insight into differences in hands on activities.

The second of five workshops surrounding the "Fundamentals of Inquiry" is called "Process Skills". This workshop aims to develop teachers understanding of the specific process skills needed to conduct investigations in science and build on their scientific knowledge. Teachers should recognise the importance of process skills on student learning of science. This workshop aims to provide teacher insight into process skills so that they can alter activities used in their own classroom to improve student abilities in utilising necessary process skills. Seven process skills are explored, i.e. observing, questioning, hypothesizing, predicting, planning and investigating, interpreting, and communicating (Exploratorium Institute for Inquiry, 2006). Within the workshop, there are 6 different workstations that the participants will complete. At each workstation, the participants engage in a particular activity and subsequently identify the process skills relevant to that activity. A series of small group and whole group discussions follow which debates the process skills involved in each activity as well as any relevant ideas about process skills that the participants have learned. Addressing each process skill and understanding exactly what is involved can elucidate any misconceptions held by the participants. For example, a discussion on the differences between a hypothesis, a prediction and an interpretation is encouraged. After this a facilitator is advised to address some of the common definitions of process skills and allow a discussion to follow on how they relate to participants views of process skills. To reiterate the importance of process skills on student learning, facilitators should provide an example where students investigate condensation and how the process skills involved faciliated learning. Participants are later asked to discuss the levels of process skills ranging from lower to higher developmental levels. They must then collaborate to discuss how activities can be altered to promote higher levels of development by the students. By the end of this workshop, teachers should have a good grasp on the importance of process skills and understand how to implement activities in a way that improves the students' process skill level. By instilling a good foundation of process skills, students can use them to conduct reliable investigations throughout science which will ultimately lead to a stronger understanding of different topics.

The third workshop, "Raising Questions" deals with training educators to ask appropriate and relevant inquiry questions in the classroom that will allow students to become engaged in activities (Exploratorium Institute for Inquiry, 2006). The first part of the workshop is hand on investigations with spheres of ice, made from freezing small balloons of water. Questions derived from investigating these spheres are written down and later critiqued in the second half of the workshop. Teachers discuss the types of questions which can lead to investigations, identifying investigable and non investigable questions as well as converting these non investigable questions into investigable ones (Exploratorium Institute for Inquiry, 2006). Discussions are also held on how to use and deal with questioning in the classroom. The aim of the workshop is to show teachers the importance in allowing students to explore their own questions while also teaching students how to ask appropriate questions which will lead to a fruitful array of new information and results.

The fourth workshop, called "Stream Table Inquiry" exposes teachers to the inquiry process first hand. It aims to create a greater understanding of inquiry as well as to motivate them to use inquiry in their own classrooms. Participants are provided with stream tables which are used to carry out different investigations addressing the both the flow and the slope. Questions arising from both are recorded, discussed, refined and allowed to be investigated further in small groups. Afterwards participants gather together their collected information and discuss their results which the facilitator later relates to scientific concepts (Exploratorium Institute for Inquiry, 2006). The workshop ends on a reflective note whereby participants review their learning experience in the workshop.

The fifth workshop deals with altering some curriculum activities so that they can be delivered using inquiry. This workshop is called "Subtle Shifts". In order for this workshop to be successful, participants must have a firsthand experience with inquiry itself otherwise they will not be able to grasp the importance of and merit in using inquiry based science teaching. In this workshop, participants carry out standardised curriculum experiments that have been altered to what is called the "Changes Activity" to allow more scope for the students to dictate the direction of investigation. In depth discussions follow, comparing the altered form of the activity to the usual format of the activity. Facilitators ask questions such as "Who determines the questions/procedure/results and analysis in the Changes activity? Why?" in order to illuminate the differences to participants and to allow reflection (Exploratorium Institute for Inquiry, 2006). Other sample activities are then presented to the group and the subtle shifts made to it in order to allow more student control over the investigation are highlighted. In this part of the workshop it is made clear to participants why the subtle shifts are made and what the teacher is trying to achieve in doing so. Teachers should then be capable to move to the next step of the workshop and collaborate together in groups to make their own changes to standard classroom activities (Exploratorium Institute for Inquiry, 2006).

3.2 IOWA Chautauqua Program

In-service teachers in the U.S. were involved in a three year IOWA Chautauqua Program (Blunck & Yager, 1996). The goal of the Staff Development Model within this program was to further teacher education on innovative methods of instruction by focusing on science, technology and society (STS) (Killion, 1999). In order to see change, the Iowa Chautauqua Program which was initially meant to be a one year intervention, began by hosting a two week leadership conference for 30 expert teachers, plus associated staff and scientists (Kimble, Yager, & Yager, 2006). Following this, a three week summer workshop was conducted for 30 pilot teachers who were exposed to a range of activities and field experiences related to chemistry, biology, physics and earth science that could be used in their own classrooms while constantly making the connection to real world phenomena. Once school resumed for the new academic year, pilot teachers tested out a module in their classrooms that had been developed in the summer (Figure 1.). The findings from the implementation phase were later discussed at a three day course in October of the same year. Issues regarding assessment techniques were also elaborated on for further use of the modules. Each district held two meetings to discuss and examine the efforts of the pilot teachers and weekly meetings were held between teachers to share ideas and collaborate. Another three day course was conducted in April of the following year to review and reflect on the findings of the program and the success of the pilot teachers. Central to the Iowa Chautauqua Program goal was to move teachers from traditional didactic approaches to more constructivist methods while placing a focus on STS. According to Blunk and Yager (1996), the Iowa Chautauqua Program increased teacher confidence in the teaching of science itself, allowed them to focus on leading questions and allowed more student input in investigations. Students benefited from lead teachers as they are more engaged, understand better the process skills needed for scientific investigations, related concepts to contexts, became more creative through questioning, hypothesising, and evaluating, and overall had a more positive outlook on the science itself through participating in a positive educational experience. Following on from this program, the Iowa Science, Sequence and Coordination (Iowa SS&C) project also ran over three years, which also showed extensive change in teachers pedagogy to more inquiry-oriented student-centred approaches and which was assessed using the ESEEM instruments (Kimble, Yager, & Yager, 2006). Similarly, Akcay (2007) assessed teacher change over the course of the IOWA Chautauqua Program using a number of instruments including the

Constructivist Learning Environment Survey (CLES) and Expert Science Teaching Educational Evaluation Model (ESTEEM).

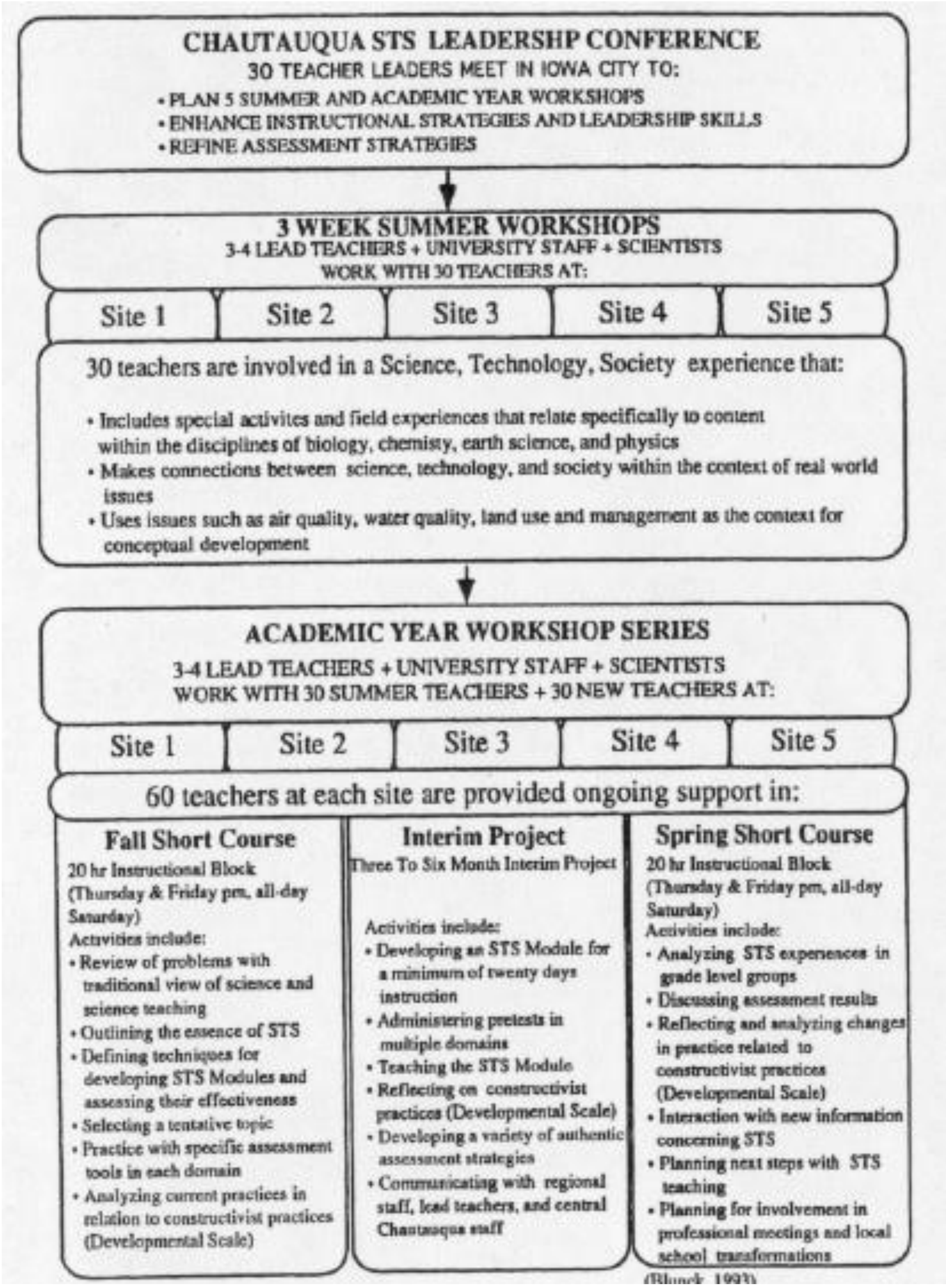

Figure 1. Iowa Chautauqua Model (Blunck & Yager, 1996).

3.3 ENVISION

ENVISION was a three year professional development project designed to train teachers in the art of inquiry based teaching of environmental science (Wee, Shepardson, Fast, & Harbor, 2007, Shepardson & Harbor, 2004). Development took place on a dual level whereby one group of participants (Level I participants) were trained by ENVISION staff and subsequently, these participants educated their colleagues at school (Level II participants). Already after the first two years, 83% of Level I participants and 68% of Level II participants began to use more inquiry based teaching. This was assessed through the use of pre-post lesson profiles of the teachers, evaluations of teaching practice and of Level II participants training, surveys, extensive interviews as well as plans and reports.

Firstly a month long summer institute was conducted with the hope to introduce teachers to the concept of inquiry, develop inquiry skills in the teachers and enhance their knowledge of environmental science. This was achieved by participation in field studies whereby teachers had to collect data to research under particular environmental protocols. They engaged in questioning key points in further laboratory experiments and finally they had to conduct their own environmental research. Teachers were required to work in groups and delineate a certain environmental topic or problem to investigate. They had to write a proposal before beginning research and provide presentations of their results which were subsequently critiqued.

Participants of the summer institute were also required to examine and discuss inquiry from the standards set forth by the National Research Council (National Research Council, 2000) as well as design possible appropriate assessment techniques for inquiry classrooms. In order to allow teachers to use inquiry throughout the academic year, and not simply try once or twice after the summer institute, teachers were asked to provide a detailed description of how they were going to implement inquiry into their curriculum. Experts in the field of inquiry science education and environmental science, called the Master Teacher in Residence (MTR) later made site visits of 1-2 days to participating teachers schools to provide assistance with any inquiry teaching issues that may have occurred following the summer institute (Wee, Shepardson, Fast, & Harbor, 2007).

Pre and post test profiles show that 83% of Level I teachers changed their method of instruction after the summer institute, particularly in the areas of “Teacher as a Guide”, “Assessment”, “Cooperative Learning”, “Designing and Conducting Investigations”, “Analysing Data, “Evidence as a priority”, and in “Scientifically oriented Questions” (Shepardson & Harbor, 2004). However, there was much less of a difference in Level I teachers attitudes towards “Justifying Explanations”, “Formulating Explanations” and “Communication”. More Level II participants were expected to be involved in the project but unfortunately only 39% on Level I teachers actually implemented the professional development on their own colleagues. Despite this, 68% of the Level II teachers that were integrated showed changes in their classroom practice following the instruction by Level I teachers.

3.4 Project INSITE

A four year professional development project named Project INSITE was set up in Indiana, USA to aid teachers in employing project based, problem centred approaches to teaching in science classrooms (Lehman, George, Buchanan, & Rush, 2006). Results from questionnaires issued before and after workshops, as well as subsequent ones given every summer afterwards showed a move from more “teacher centred” approaches to more “learner-centred” approaches. To aid teachers in continually implementing inquiry in their classrooms three “phases of activity” were set up each year.

Firstly, a three week summer institute for in-service and pre-service teachers was conducted in each year. This was the most important part for teacher development as it introduced them to and reiterated the importance of project-based science and aimed to “help them develop their knowledge, skills and dispositions to implement their own project based science units in the classroom” (Lehman, George, Buchanan, & Rush, 2006).

During the summer institute, they engaged in project based activities through the perspective of the learner. They also visited places such as Eli Lilly, National Weather Service and the U.S.G.S. where they interacted with other scientists and learned where science is used in industry. Other workshops that aimed to improving their pedagogical content knowledge in areas such as co-operative learning and alternative assessments were run as well as those committed to improving their IT skills. The teachers also eventually helped create new units together about certain topics in science that they could teach in the classroom through inquiry.

During the academic year, teachers were encouraged to use what they had learned, to teach inquiry in the classroom. To provide support for teachers in this time, other teachers experienced in project based learning shadowed the participating teachers to help them continually implement and maintain inquiry based classrooms.

A number of meetings were set up during the year as well as a weeklong gathering in the following summer to discuss the year’s progress.

3.5 BIOMIND Programme

Similarly, several meetings per year were organised by the Israeli Ministry of Education for teachers involved in their Biomind programme (Zion, Cohen, & Amir, 2007) for participating teachers. This was reported as a positive experience for teachers where they were allowed to lead discussions on their implementation of inquiry, the obstacles they encountered as well as the solutions used to overcome these problems. The Biomind programme itself was designed integrate inquiry based science into schools, in response to evidence that most Isreali classrooms are teacher directed. Introductory workshops aimed to develop teachers scientific and pedagogical content knowledge and allowed teachers to learn both the principles of inquiry as well as those of the new Biomind program they were required to implement in their classrooms.

Pre and Post summer institute questionnaire issued every year showed a move from teacher centred to student centred instruction. These questionnaires consisted of 12 categories that assessed participants attitudes towards the teaching of science and towards computers. Certain items on the questionnaires referred to teacher centred practices whereas others reflected a more student centred approach and participants were required to respond how much they agreed with each item/statement on a 5 point Likert scale ranging from "Strongly disagree" to "Strongly agree". After 3 of the 5 summer institutes there was a significant shift in the attitudes to more student centred practices. For example, three of the teacher centred items (Category 4, 6 and 10) stated, "There are certain facts in science that children should know", "Science should be a matter of telling children what they are to learn" and "Teacher should be the authority on the classroom; they ought to be there to teach and the students should be there to learn from them". Teachers responded more negatively to these items after the three institutes compared to beforehand. Similarly, by the last summer institute, few teachers responded to Category 12, "The teachers should be the sole determiners of activities: they should plan and evaluate each day's work". Some teachers reportedly felt empowered and confident in teaching project based science after just 1 or 2 years of the programme. Others felt that, although students responded positively to the new method of instruction, time issues may have interfered with students fully grasping concepts while completing projects. Many of the advantages and, ultimately, the changes seen in teacher practice through the completion of this programme were as follows:

- Teaching better through new methods
- Becoming a facilitator and allowing a more student centred class to develop
- Collaboration with others
- Developed science content knowledge
- Improved confidence in teaching

3.6 "Teaching Science: Just Do It!"

Melear et al (2000) argues that research experience should be an essential component of pre-service teacher education. A course, *"Teaching Science: Just Do It!",* was run in the University of Tennessee by Melear *et al* (2000) over one semester for pre-service science teachers in order to expose them to long term inquiry that they could eventually use in their own classrooms. They conducted investigations six hours a week in labs/classes and were supervised by scientists. The project was aimed at allowing teachers to learn how to develop appropriate research questions and design sophisticated experiments to answer those questions rather than making incomplete investigations based on irrelevant or unsuitable questions. Students were given a sample of "unknown" dry spores were asked to collect information about the unknown sample over time by formulating questions about the spores and subsequently planning and conducting experiments that revealed the spores characteristics over time. Scientists gave minimal guidance to ensure progress and weekly/biweekly group discussions and reflections were hosted to discuss any ideas or results. One of these sessions involved presenting a research article and discussing the experiments, analysis and interpretations involved. Their progress was further analysed using laboratory notebooks, reflective journals and videotaped class sessions.

During the project most students became irritated and disillusioned due to the lack of guidance as well as the fact that results didn't work out as hoped. One student suggested that he felt lost with so little structure after having experienced so much of structured didactic teaching. However he also mentioned that "the main problem is ignition for all of us" suggesting this is the first obstacle for all teachers introduced to inquiry.

The tensions in the class were reportedly only temporary however and eventually everyone contributed different aspects to the group work. Understanding that this tension was the most critical incident in the course, students in future courses will be encouraged that the feeling of tension was normal. The life of a scientist is full of “frustrations, ambiguities and confusion” (Melear, et al., 2000) but as one student put it,

“I think that if the tensions were not there, I would not have learned as much as I did.”

By the end of the project, the participants were asked to identify they key differences between this type of class and other science classes they had experienced before. All participants reported that it had been a positive experience overall and by comparison to didactic teaching it allowed them to think for themselves and use logic, to have the freedom to express ideas to one another and collaborate as well as work independently in their own direction. All students were introduced to the importance of repeatability in experiments and making replicates which is a key factor in the work of scientist. They recognised that their own motivation determines whether they will learn or not but even students that socialised more than worked successfully designed and presented experiments.

Through this course, pre-service science teachers encountered and subsequently overcame obstacles never exposed to them before in more traditional teaching classes. In the process they learned important inquiry skills such as developing their own open questions, collaborating with peers, planning relevant investigations, replicating them, critiquing, explaining and finally presenting results.

3.7 Teacher Intervention Programmes

In a research project by Laius, Kask and Rannikmae (2009) two teacher intervention programmes were carried out to assess change in teacher attitudes toward inquiry based science teaching over an eight month period. These two interventions promoted different aspects of scientific inquiry. Study A, focussed on advancing 8 participant teachers’ skills in implementing inquiry laboratories, and assessing and relating students acquired process skills in the classroom to skills in everyday life. Study B, focussed on enhancing 12 teachers skills at using socio-scientific issues to promote student alternative thinking and creativity. While both studies were separate and subtly different they both stressed the importance of student centred approaches, the interdisciplinary nature of science, relevant knowledge, collaboration with peers to create teaching materials and most importantly inquiry process skills. Teachers from both studies took part in 4-5 in service meetings which lasted between 1-2 days each. Teachers were also provided with resources to carry out inquiry activities and were asked to later design their own for use in their classrooms. Teachers were assessed using questionnaires and semi structured interviews both before and after the program. The teaching materials they themselves developed for use in an inquiry classroom were also analysed. Four aspects of teacher change, compiled by researchers, were found for both Study A and Study B, though they were different for each study.

For study A, these four categories were “The goal of teaching chemistry”, “Teaching strategy”, “Instructional Material” and “Obstacles Observed”. Within these categories were three hierarchical subcategory statements with 1 being the least inquiry oriented to 3 being the most inquiry oriented. 1 were named “non adapters” and encompassed the teacher-centred didactic approach; 2 were called, “teacher inquiry users” which involved teacher centred structured inquiry users and finally 3, “student inquiry users” were the most student centred inquiry oriented sub category. 6 out of 8 teachers displayed a change from lower sub categories to higher sub categories. Three of the teachers that reached the fully inquiry oriented sub category also showed the change in the majority of other categories. Inquiry materials created by the teachers improved vastly in quality after the intervention and all teachers understood the importance of relating scientific concepts to real life issues. Within the “Goal of teaching chemistry category”, most teachers moved from lower to higher subcategories in “1. Disseminating knowledge; 2. Disseminating knowledge and development skills needed in chemistry lessons; 3. Development of student as future citizen”. Similarly there were positive changes seen in the subcategory which listed, “1.The aim of experimental work is illustrating theory; 2. The aim of experimental work is the development of manipulative skills needed in chemistry; 3. The aim of experimental work is the development of skills needed in everyday life”.

In the “Teaching Strategy” category, the most positive changes were seen in subcategories which described a move to using real life problems/issues to motivate students and to teachers valuing collaborative work rather than individual work. The “Instructional Material” category saw positive changes in teacher attitude towards using socio-scientific issues to solve problems rather than relying on textbooks for instructional material. Similarly, using real life situations as comparisons throughout the lessons was valued greatly by teachers after the intervention compared to beforehand. The final category in Study A to see change in teacher attitude was related to obstacles met or avoided. 6 out of 8 teachers either encountered less problems or none at all with implementing inquiry in the classroom.

Study B consisted of categories, “Teaching Approach”, “Inter-disciplinarity and communication”, “Competency”, and “Overcoming the barriers”. Similarly they consisted of three hierarchical subcategories ranging from 1 to 3, or from “non adapters” to “student inquiry users” respectively. The teaching attitude and practice overall improved greatly after the intervention. Under the first category (“Teaching approach”) there was a considerable shift in teachers starting lessons with simply a textbook heading to instead using a social issue. Teaching material used also improved to be more problem based rather than teaching just scientific content and its application. As in Study A, teacher in Study B also saw the importance of students working in teams rather than working alone, which fell under the “Competency” category. Similarly, creative and reasoning skills were focussed more acutely on by teachers who learned to not just explain concepts but to assess student reasoning and creative skills also. Teachers Collaborative work showed substantial changes as those teachers who opted to work alone did not display much of a positive change compared to teachers who worked together during the in-service programme.

3.8 Inquiry Based Demonstration Programme

An 18 month programme, called the Inquiry Based Demonstration Programme (IBDC), attempted to change teacher beliefs and practices within two groups of participants; induction teachers and experienced teachers (Luft, 2001) but like so many professional development programmes designed to increase awareness and skills used to implement inquiry, the process was laborious and did not yield very significant results. The Teachers' Pedagogical Philosophy Interview (TPPI) was used to assess change and was issued to participants before the summer in service workshop, during the academic year and again afterwards. Teachers were also observed in their classrooms by their peers and demonstrators of the programme when using an "extended inquiry cycle", which is a minimum 3 day problem solving cycle. Observers used the rubric entitled the Extended Inquiry Observational Rubric (EIOR). The categories in the rubric which the teachers were assessed on were based on their practices and on the effect these had on their students:

- Cooperative learning
- Teacher as a guide
- Assessment
- Student communication and action
- Inquiry question
- Designing and conducting a scientific investigation
- Gathering and analysing data
- Sharing of extended investigation

A six day pre-programme was run before the assessed academic year. It consisted of a one day introduction to inquiry based science education in Spring and then during the summer followed a five day workshop whereby participants were exposed to inquiry first hand and later were required to develop an extended inquiry cycle which they would use during the upcoming academic year. While employing extended inquiry cycles to their lessons teachers could also avail of follow-up activities which allowed them to review and improve their teaching of inquiry. These activities involved teachers observing other participants classes in action, receiving feedback from both peers and coordinators of the programme, being involved in online communication with directors and other participants. Teachers also attended 5 one day meetings throughout the year to discuss obstacles met and possible solutions as well as expand on their knowledge of inquiry skills needed to conduct extended inquiry cycles.

The interviews and observations produced conflicting results. The TPPI revealed that teachers responded with more didactic traditional beliefs about science instruction after the programme compared to before yet they became more adept at implementing extended inquiry cycles based on the EOIR. However all participants better understood the skills involved in implementing an inquiry classroom and what was expected of both the students and the teacher. Many participants resorted back to traditional methods of teaching having received particularly unmotivated students who refused to engage with the extended inquiry cycles. Teachers that did implement the extended inquiry cycles reported them as being their favourite experiences of the year as they learned new methods of instruction that they could apply to a number of situations and enjoyed planning further inquiry lessons. Witnessing the effect these extended inquiry cycles had on their students was also reported positively by participants as was the level of support they received from the coordinators throughout the programme. Feedback was greatly appreciated and allowed teachers to refine their teaching further over the course of the project.

3.9 Lotter, Harwood and Bonner Study

Clearly not all professional developments projects or interventions are effective enough in changing teacher's pedagogy as both a practice and belief system (Lotter, Harwood, & Bonner, 2007). The level of inquiry used by a teacher is strongly governed by their core conceptions. Addressing and understanding these conceptions can determine the openness of a teacher to inquiry and how different issues may affect them while implementing inquiry. A study by Lotter, Harwood and Bonner (2007) investigated three biology teachers' core conceptions and how these affected their teaching of inquiry even after a professional development project. The professional development involved a 2 week summer research institute and three academic year workshops. In the summer workshop, the teachers were engaged in inquiry research and developed inquiry activities on topics in biology that were considered difficult to teach students effectively. These topics were labelled, "Bottlenecks". The researchers identified that the three teachers differed in their belief systems across 4 different categories:

1) Their conceptions of Science
2) Their conceptions on the purpose of education
3) Their conceptions of their students
4) Their conceptions of effective teaching

The research aimed to answer a number of important questions about teacher conceptions and the significance it had on teacher change: What were their conceptions of each of the parameters listed above? What were their views on inquiry? How did they change over the course of the professional development programme and finally, how did their conceptions influence their teaching of inquiry?

Interviews were conducted before and after the summer workshops as well as after the programme as a whole in order to track teacher change, if any. Charles, one of the participants, considered science to be a collection of facts that people should know off by heart. Conversely Jane and Steve, the other two participants, identified science as an active process involving questions, curiosity and an array of important process skills. Steve however constantly correlated concepts with real world problems, unlike Jane. All three teachers believed that the purpose of education was to train younger generations for the lives around them and ahead of them. However, Charles viewed this as providing students with content knowledge which he assumed would help them progress through life. Jane believed preparing students for the outside world involved students participating in work and working hard at it, even if their content knowledge was lacking. Students not taking part or not attempting to contribute work were considered by Jane a failure in their education. Steve, on the other hand, believed that by exposing students to a range of experiences in the classroom, it would provide the students with the skills and tools needed in life to succeed. He adopted a student centred approach whereby student discussions and students voicing their opinions or queries were a regular occurrence in his classroom. As regards teacher conceptions of their students, Charles believed his students would flounder without his direct approach to instruction. Jane believed that students could become interested in education through a number of teaching methods, including inquiry. But not ruling out didactic methods whereas Steve believed that students were passive learners that didn't have any inquiry oriented skills to solve problems. As for their views of effective teaching, Charles considered teacher directed classrooms as being the most advantageous for student learning of science content. Jane reiterated her beliefs that an education which makes students work hard is a success. Steve believed that inviting a student centred atmosphere in a classroom allows students to develop important thinking processes and skills needed for science.

After the professional development project teachers better understood inquiry as thinking process. Jane believed that she incorporated more inquiry in her classroom than she originally thought before the summer institute and in those two weeks she discovered that inquiry need not be a lengthy process but that it can be introduced through short projects or investigations which would also be of benefit to her students. Steve's core conceptions changed little but ceased to believe students as passive learners and that there are a number of ways to engage and motivate students so long as the teacher is willing and confident that the task can be achieved. Charles remained teacher directed largely after the summer institute but understood better the idea of inquiry as an important thinking process which students should experience.

After the programme researchers also found that the teachers' core conceptions greatly influenced their implementation of inquiry. Jane's firm beliefs that both didactic and inquiry methods can educate students effectively meant that, even after a professional development programme, she refused to change her core conceptions or reflect on her teaching methods critically. Although she implemented some of the inquiry lessons learned during the workshops she failed to use them as a platform to produce her own. Conversely, Charles, unfamiliar with inquiry teaching, considered the workshop to provide him with a new repertoire of methods which he could use to educate his students. His inquiry classrooms became gradually more student centred but with a teacher directed approach to the types of questions and projects involved in the classroom. However, by the end of the year he was comfortable and confident enough to allow a student centred activity to enfold. This displayed an openness and enthusiasm in trying new methods of teaching that was so necessary to the process of change. Steve continued to incorporate inquiry in his classroom after the summer institute, changing only the length of his projects and the subject matter to a more long term broad topic needed to be answered by his students.

The teachers' core conceptions were also found to affect how they dealt with problems encountered while teaching through inquiry. Jane, who in theory promoted inquiry teaching as an effective method, struggled with allowing student directed research. She felt unconfident with delving into areas of science she knew little about herself and believed her students learning would be inhibited without her constant guidance. Attempts to incorporate student centred inquiry activities were met with an unwillingness to advocate her position as leader of the classroom. Charles also displayed this resistance as he believed his students would fail without his direct instruction. He was more preoccupied with controlling student behaviour and classroom management than allowing student discussion to enfold. He also only used one inquiry lesson from the workshops. His beliefs of didactic instruction, stemming from long term use, were difficult to waver and only at the end of the academic year did he feel comfortable enough to employ a student centred approach and conduct an inquiry activity. Steve, unlike Jane and Charles, viewed their barriers of inquiry as issues that he could overcome through reflection, dedication and a positive attitude.

Reforming science instruction involves addressing and understanding numerous factors which can act as obstacles along the way. Core conceptions are one such important factor to consider when attempting to change teacher pedagogy as they can act to either impede or encourage change from traditional methods of teaching to more reformed instruction such as inquiry.

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