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Challenges in the transition to large-scale reform in chemical education

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ABSTRACT

It is not often that research accompanies large-scale science education reforms. In order for an educational reform to be sustainable and for its implementation to grow from small to large scale, one should account for policy, culture, and assessment. This study investigated a large-scale national-level chemistry curriculum reform in Israeli high schools, which emphasized higher order thinking skills, learning in context, visualization, and chemistry understanding at four levels. By the end of a five-year-long intervention, the implementation encompassed 4031 participants in the reformed curriculum, representing approximately half of the chemistry majors in Israel. The study investigated the effect of the nationwide implementation on (a) teachers' challenges in terms of the transition to a reformed-based curriculum that emphasizes thinking skills in a large-scale setting and (b) students' knowledge, chemical understanding, and thinking skills in specific questions in the national matriculation examination, based on an analysis of the examination data. This paper focuses on one of the new learning units, *Taste of Chemistry*, as a case in point to demonstrate higher order thinking skills, such as graphing skills and modeling skills. We analyzed the following sources: (1) interviews with teachers, (2) questions from the traditional matriculation examinations, (3) questions from the new matriculation examination, which featured higher order thinking, (4) the number of students who responded to the reformed examination compared with the number of their peers who responded to the traditional one, and (5) students' scores in the two examination versions. We classified the reform scale-up challenges into two types: (a) issues related to teachers' pedagogical content knowledge and assessment knowledge and (b) system-related policy issues. Between 2007 and 2010, the number of students studying the reformed curriculum increased exponentially, while the failure rate decreased and the percentage and average scores of students who elected to respond to the *Taste of Chemistry* question in the matriculation examination increased. We conclude that the reform was successful due to its emphasis on (a) the close collaboration between the three stakeholders, which included two academic institutions, the Ministry of Education, and the teachers and (b) on clear, consistent policy, longitudinal support, and the implementation process.

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1. Introduction

Few large-scale science education reforms are accompanied by research. Not only are such studies costly and difficult to carry out, but it is also rarely possible to conduct and follow large-scale professional development over an extended period. For a reform to be defined as large scale, it must involve (a) all schools in at least one whole district; (b) hundreds of schools implementing a particular model of change; or (c) national or state-level interventions involving most schools (Fullan, 2000). The present study was conducted in the setting of reforming the national Israeli high school chemistry curriculum.

Science education curricula in Israel are determined by the various science subject matter committees. In chemical education, this National Chemistry Committee includes chemists, chemical educators, the national chemistry superintendent, district-level mentors, and senior chemistry teachers. Together, they discuss and agree on both the content and pedagogy. These decisions influence all high school chemistry students, since at the end of 11th and 12th grades all chemistry majors and honors students are required to pass the matriculation examinations. As part of a fundamental reform in the chemistry curriculum in Israel over the last decade, several learning modules were developed. This reform was in line with the Ministry of Education national Pedagogical Horizons for Learning program (Zohar, 2008). This program set a goal to move from small-scale isolated projects that encourage the learning of higher order thinking skills to a systematic educational change that promotes the learning of such skills. Examining three national education systems, Gallagher, Hipkins, and Zohar (2012) gained insights into issues required for supporting thinking-oriented teaching. Such focus on teaching for 'thinking' requires a comprehensive vision that is stated explicitly. The national chemistry education reform, which the Ministry of Education's Chief Chemistry Supervisor and the National Chemistry Committee led, was one of the first to implement this educational change (Barnea, Dori, & Hofstein, 2010; Zohar, 2008).

1.1. The reformed chemistry curriculum vs. the traditional one

The first goal of the Israeli policy-makers for the reformed chemistry curriculum was the "less is more" paradigm, advocated in the "Benchmark for Science Literacy" (American Association for the Advancement of Science, 1993). This paradigm had guided curriculum developers and teachers' mentors in facilitating deep understanding among students. The paradigm assumed that by learning fewer topics that are relevant to the students, the students and teachers would have more time to concentrate on developing deeper understanding through the learning of higher order thinking skills (Dori & Sasson, 2008; Dori, Sasson, Kaberman, & Herscovitz, 2004; Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005).

A second goal was making the learning more relevant to the students in order to address a significant decline in the number of students choosing to learn chemistry. To this end, a context-based approach was chosen while developing the new chemistry curriculum (Shwartz, Ben-Zvi, & Hofstein, 2006). This was a research-based decision, since research has shown that courses and topics that emphasize a context-based approach as well as an approach which integrates different science disciplines, motivates students, and answers their most common question, "What do I need this for?" (McBroom & Oliver-Hoyo, 2007; Shwartz et al., 2009). For example, situating chemistry in a context that is relevant to students' lives embraces the integration of different disciplines such as industry, economics, social sciences, and biology (Hofstein & Kesner, 2006; Schwartz, 2006), making learning more attractive to students. This second goal is related to the first one, since context-based pedagogy promotes deep understanding and the learning of higher order thinking skills by focusing on student-centered activities and inquiry-based laboratory investigation while minimizing traditional lectures and 'cook-book' type laboratories (Schwartz, 2006).

Each topic in the reform was established in a context-based environment, and included an entire unit of inquiry-based chemistry laboratory. Examples of context-based chemistry are food chemistry as a context for learning organic chemistry and the human body as a context for learning oxidation–reduction and acid-based reactions. These examples demonstrate the approach of using applications as starting points for the development of scientific ideas (Bennett, Lubben, & Hogarth, 2007).

Comparing the reformed chemistry curriculum to the traditional one, it is important to notice explicitly the differences and similarities between the two. Similarities included the number of hours devoted to chemistry and the content of the core subjects: chemical bonding and structure, acid and base structure and reactions, redox reactions, and organic chemistry. However, there were three main differences between the reformed chemistry curriculum and the traditional one. The first important difference was the change of the fifth unit from a theoretical one to an inquiry-based laboratory unit. The laboratory in the traditional curriculum was rarely taught, and if so, it was implemented in a 'cook-book' approach as a half unit. The second difference was the context in which the core ideas were presented in the reformed curriculum. This context-based aspect was not an integral part in the traditional chemistry curriculum, where content core subjects were presented in a theoretical way with almost no relevance to students' lives. The third significant difference is the emphasis on learning higher order thinking skills, including the ability to transfer between various graphic and molecular representations, developing visualization and inquiry-based skills, and explanations that use as many of the four levels of chemistry understanding as possible.

The four chemistry understanding levels – the symbolic, macroscopic, microscopic, and process (Dori & Hameiri, 2003; Gabel, 1998; Jhonstone, 1991; Kaberman & Dori, 2009; Shwartz, Dori, & Treagust, 2013) – are essential and crucial for meaningful understanding of substances, phenomena, and processes in chemistry. The macroscopic level refers to the description of the phenomena by our senses, such as vision, smelling, and hearing. The microscopic (also referred to as the