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A three-attribute transfer skills framework – part II: applying and assessing the model in science education

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In an era in which information is rapidly growing and changing, it is very important to teach with the goal of students' engagement in life-long learning in mind. This can partially be achieved by developing transferable thinking skills. In our previous paper – Part I, we conducted a review of the transfer literature and suggested a three-attribute transfer skills framework presented graphically as a cube. The goals of this paper – Part II are (a) to investigate the application of the three-attribute transfer skills framework by conducting two studies; and (b) to demonstrate the value of the framework as a tool for design of assignments and assessment of students' transfer skills. In this paper, we have applied the three-attribute transfer skills framework to design assignments and to assess middle and high school students. In order to achieve the first goal we conducted two studies: (1) investigating high school chemistry students in a computerized laboratory setting, and (2) exploring middle school students who were exposed to a science enrichment program. Study 1 took a case-based chemistry approach and included assessment of high school honor chemistry students' transfer skills. In Study 2, we evaluated the transfer skills of ninth grade students who had participated in a science enrichment academic program with emphasis on physics and we compared boys to girls. Findings of Study 1 indicated an increase in students' far transfer skill as expressed by the progress students made in transferring knowledge from chemistry to other science domains and by using more chemistry understanding levels in their responses. In Study 2, we found that the near transfer skill of middle school boys was significantly higher than the same skill among girls who participated in the same enrichment program. Both parts, the review and the three-attribute transfer skills framework (previous paper – Part I) and the research (this paper – Part II), contribute to narrowing the gap between the theory of transfer, empirical research, and the practice of transfer in science classrooms.

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Introduction

Transfer refers to students' ability to recall knowledge and skills and to apply them in new learning situations (Salomon and Globerson, 1987; Salomon and Perkins, 1989; Detterman, 1993; Dori and Sasson, 2013). Transfer is linked closely to how knowledge is represented in students' memories. Educators aim to teach knowledge and skills that students will use in the future when they are not in school. Knowledge and skills acquired in the classroom are valuable for one's entire life (Halpern and Hakel, 2002; Könik *et al.*, 2009). Therefore, transfer skills are part of life-long learning ability. Life-long learning emphasizes the value of learning during all phases of life while learners make flexible choices in order to reach desired goals (Joosten-Ten Brinke *et al.*, 2008) and transfer skills and experiences from their previous experiences to their new careers (Tigchelaar *et al.*, 2010). Educators aim to teach knowledge and skills that students will use in the future when they are not in school. Halpern and Hakel (2003) suggested some principles to enhance long-term retention and transfer. One example is practice at retrieval – learners must generate responses with varied applications so that recall becomes fluent and therefore, it is more likely to occur across different contexts and content domains. They also emphasized the importance of varying topics as well as the conditions under which learning takes place (Schönborn and Bögeholz, 2009). Training and teaching modes may affect transfer. Karbach and Kray (2009) argued that although near transfer has been proven to be possible among different age groups, conditions supporting far transfer may differ for diverse types of training. Additionally, the

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lifespan development of these effects is still not clear. Empirical literature has reported difficulty in achieving transfer (De Corte, 2003). One of the main challenges in transfer study is the question of measurement. The literature describing empirical studies on transfer skills lacks a sufficiently methodological framework (Sasson and Dori, 2012; Dori and Sasson, 2013).

In the first part – Part I – of our two-part study (Dori and Sasson, 2013), several theoretical aspects of transfer skills were demonstrated along with a three-attribute transfer skills framework (3D framework). In Part I we also presented the three attributes of transfer in a 3D cube, during which the learning situation (*i.e.*, the student is exposed to a new task) changes from near to far transfer. The three dimensions, namely Task Distance – TD, Interdisciplinarity – I, and Skill Set – S, define near or far transfer (see Fig. 1). Near transfer occurs when the learning situation is similar to the previous learning situation – TD, is low; the learning situation draws on a single discipline or is based on closely-related content – I is low; and the learning situation requires application of a relatively small set of skills – S is low. In contrast, far transfer occurs when a student has to perform in a new and different learning situation – TD is high; that requires application of several skills – S is high; and knowledge from one or more disciplines other than the one in which the learning took place originally – I is high. The combination of these three complex attributes gives rise to a spectrum of transfer task difficulties (Sasson and Dori, 2012; Dori and Sasson, 2013).

The goals of this paper – Part II – are (a) to investigate the application of the three-attribute transfer skills framework by conducting two studies; and (b) to demonstrate the value of the framework as a tool for design of assignments and assessment of students' transfer skills. In this paper, we have applied the three-attribute transfer skills framework to design assignments and to assess middle and high school students.

First, we present models of transfer (see Table 1) and assessment methods that have been used in the literature to evaluate students' transfer skills (see Table 2). Next, we focus on two empirical studies in chemistry and science education which demonstrate the application of the three-attribute transfer skills framework in practice and research. The two studies we conducted in order to achieve the first goal were: (1) investigating the application of the transfer skills framework in high school chemistry students in a computerized laboratory setting, and (2) exploring the use of the transfer skills framework in middle school students who were exposed to a science enrichment program. We designed a variety of transfer tasks and used these tasks to assess students' transfer skills. In Study 1, we evaluated the extent of change in transfer skills from pre- to post-questionnaire since the students used the case-based approach during more than one semester. In Study 2, we took a snapshot of students' transfer skills and compared boys to girls. Finally, we considered the potential value of the proposed transfer framework to instructional designers and teachers and the science education community at large in the Discussion section.

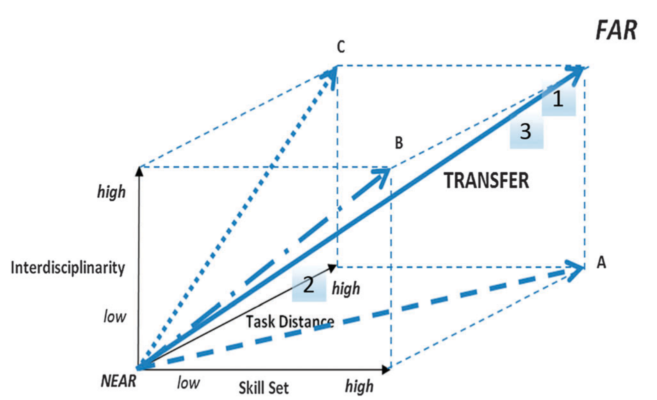

Fig. 1 Characterization of far and near transfer assignments in the 3D transfer skills framework.

Theoretical and empirical background on transfer assessment

The perspective adopted by transfer researchers usually starts with pre-defining the main concept that should be transferred from one learning situation to another and then researchers investigate it in order to find evidence for transfer. Studies based on these traditional views of transfer often show little support for the occurrence of transfer (Rebello *et al.*, 2005). In the absence of clearly defined models of evaluation of transfer skills, research on transfer is sometimes criticized for being overly dependent on the perspective of the researcher and reliant on models of expert performance, which are often difficult to find (Bransford and Schwartz, 1999; Carraher and Schliemann, 2002). In our literature review, we found only six articles that presented models of transfer which addressed different communities. As shown in Table 1, Cornford (1991), Wallace (1992), and Eraut (2004) suggested models for practice of transfer in workplaces. Yelon (1992) presented a model that accounts for affective factors which influence students' learning. Smagorinsky and Smith model (1992) is based on the nature of knowledge transfer in composition and literature, while Sadler and Fowler (2006) focused their model on the transfer of knowledge as students advance from novices to experts. All models deal with theoretical aspects of transfer, describing variables that influence transfer skills or different stages of transfer. The contribution to the instructional design processes of learning assignments is limited. Wallace's three-dimensional model (1992) included performance transaction and environment features in addition to the skill dimension that was included in our model. We defined in our model three specific dimensions of the learning assignment: skills (S), task distance (TD), and interdisciplinarity (I). Educators can design the learning environment and evaluate their students' performance by using our 3D model and the specific dimensions; therefore, the feasibility of our 3D model is relatively high.

Failures to achieve transfer have been reported in the empirical literature (De Corte, 2003). Students often fail to associate knowledge from previous learning to potentially applicable cases at hand (Perkins and Salomon, 1988; Bassok

Table 1 Models of transfer – cognitive components

Model	Citation
Four variables are important influences on transfer: • The nature of what is being transferred. • Differences between the contexts. • The disposition of the transferee. • The time and effort devoted to facilitating the transfer process. The transfer process involves five inter-related stages: • The extraction of potentially relevant knowledge. • Understanding the new situation. • Recognizing what knowledge and skills are relevant. • Transforming them to fit the new situation. • Integrating them with other knowledge and skills in order to think/act/communicate in the new situation.	Eraut (2004)
The threshold model of content knowledge transfer: • Supports the hypothesis that argumentation is related to content knowledge, but the relationship is nonlinear. • According to this model students develop their content knowledge while they advance from novices to experts, demonstrating a progress from "basic rules" to "advanced knowledge" and argumentation transfer.	Sadler and Fowler (2006)
The nature of knowledge transfer in composition and literacy: • The case for general knowledge transfer is most widely substantiated at the elementary level. • The case for task-specific knowledge transfer is best supported at the secondary and college level. • The community-specific knowledge transfer is most typically investigated at the upper levels of schooling and in the professions.	Smagorinsky and Smith (1992)
An incremental transfer model: • The three-dimensional model includes skill process elements, performance transaction, and the environment features. • The transfer model defines five stages of transfer: skill initiation, skill constructing, initial skills practice, near transfer practice, and far transfer practice.	Wallace (1992)[a]
A learning model for achieving transfer which refers to: • Motivation of learners before, during, and after learning/training. • Awareness of the use of the learned skill. • Skill and learning/teaching strategies. • Support *via* mentoring or supervision of novices.	Yelon (1992)
A sequential skill practice model, which includes three stages: • The acquisition of the basic skill. • The development of the generalized application. • Transfer of the generalized skill to a different setting.	Cornford (1991; 2002)

[a] Wallace (1992) is a conference paper, not published in a peer-reviewed journal.

and Hoyyoak, 1993). Although no definitive answers have been offered as to why transfer has been found in some studies while not in others, possible answers or alternative explanations might lie in (a) the theoretical and methodological differences between the various studies (Butterfield and Nelson, 1991), and (b) the differences between the assessment methods applied to the investigation of students' near and far transfer skills.

Part I of our two-part study centered on the three-attribute transfer skills framework. We also presented an investigation of the relationship between educational or instructional methods and one or more of the three proposed transfer skill attributes. In this paper, we emphasize the assessment methods that were used in order to evaluate students' transfer skills. Analysis of papers that focus on investigating applications of transfer has revealed that several instructional methods affect the acquisition of transfer skills amongst learners: problem-based learning (Masui and De Corte, 1999; Adams *et al.*, 2003), cooperative learning (Zohar, 1994), case studies (Sasson and Dori, 2006, 2012), metacognitive instruction (Veenman *et al.*, 2004), and learning environments that emphasize specific thinking skills, such as posing questions (Lee, 1980), inquiry (Lawson *et al.*, 2000; Keselman, 2003), and reasoning (Lin and Lehman, 1999; Sadler and Fowler, 2006). Twenty-two papers were selected as empirical research studies for this part – Part II – since they deal with assessing transfer skills. Considering the assessment methods of these papers, we found that they used interviews (in-depth unstructured or semi-structured), questionnaires, or audio-taped discussion analyses as methodological ways of evaluating transfer skills. However, we found detailed descriptions with examples of these assessment methods in only eight papers (40%) while general descriptions of methods were found in additional ten papers (50%). In two papers (10%), no reference to evaluation methods was mentioned. Table 2 presents results of the empirical research literature on transfer skills with an emphasis on assessment methods.

The literature describing empirical studies on near and far transfer skills lacked sufficient methodological framework. In view of the lack of coherence and consistency in the body of knowledge on transfer and the need to narrow the gap between theory and practice, in Part I of our two-part study, we suggested a theoretical framework in which transfer is characterized by the three transfer attributes described earlier. This theoretical

Table 2 Empirical research literature on transfer skills – learning environments, assessment methods, and transfer dimensions

Learning environment	Assessment method(s)	Transfer dimensions of the research design	Citation
Problem-based learning	General description In-depth unstructured interviews were conducted, in which learners were asked about their ability to apply skills they had learned.	Skill set	Adams *et al.* (2003)
	General description A questionnaire about the study activities and experiences in the course was administered. Questions were aimed at detecting self-judgment behavior. Students were asked to provide a reasoned explanation of their position regarding transfer occurring between courses.	Interdisciplinarity, skill set	Masui and De Corte (1999)
	General description Questionnaires assessing knowledge in physiology, attitudes and skills were used. Both groups received the questionnaires before training and 4 month post intervention.	Skill set	Young *et al.* (1998)
	No reference to assessment methods	Skill set	Norman and Schmidt (1992)
Inquiry-based learning	General description with one example Pre and post tests in which transfer tasks were included.	Skill set	Keselman (2003)
	Detailed description and examples A transfer problem which required hypotheses testing and involving unobservable casual agents was administered. The context of the problem was not explored in the course.	Skill set	Lawson *et al.* (2000)
	Detailed description and examples Interviews were conducted with individual visitors, leading them through a randomly assigned inquiry activity and asking them a final assessment question.	Skill set, task distance	Sue (1997)
	General description with examples In both the pre and the post-tests, near and far transfer measures were used.	Task distance	Muthukrishna and Borkowski (1995)
Question posing	Short description with one example Lateral and vertical transfer problems were used for assessing the transfer skill.	Skill set	Lee (1980)
Case studies	Detailed description with examples Pre and Post case-based questionnaires and interviews were conducted.	Interdisciplinarity, skill set, task distance	Sasson and Dori (2006, 2012)
	No reference to evaluation methods	Skill set, task distance	Lohman (2002)
	General description Science and chemistry background tests, chemistry achievement tests, and case-based questionnaires were used.	Skill set	Arzi *et al.* (1986)
Instructional-based learning	Detailed description and examples An analysis of audio-taped discussions was carried out, and pre and post-tests were administered.	Interdisciplinarity, skill set	Zohar and Nemet (2002)
	General description with examples Five tests were administered, using both experimental and control groups. Out of the five tests, two were used to measure the near transfer effect and three for assessing the far transfer effect.	Skill set, task distance	Lee and Thompson (1997)
	Detailed description Pretest-training-posttest design. Task-switching training to structurally similar tasks and its modulation by verbal self instructions and variable training, as well as far transfer to structurally dissimilar 'executive' tasks and fluid intelligence.	Task distance	Karbach and Kray (2009)
Reasoning instruction	Detailed description Semi-structured interviews related to genetic engineering issues were conducted.	Skill set	Sadler and Fowler (2006)
	General description with examples Two types of problems – contextually similar (near transfer) and	Interdisciplinarity, skill set, task distance	Lin and Lehman (1999)

Table 2 (*continued*)

Learning environment	Assessment method(s)	Transfer dimensions of the research design	Citation
	contextually dissimilar (far transfer), were used for assessing students' ability to identify variables to be manipulated or controlled, to explain experimental purposes, to interpret experimental results, and to propose an effective experimental design.		
Metacognitive instruction	General description Computerized transfer tasks were administered.	Interdisciplinarity, skill set	Veenman *et al.* (2004)
	Detailed description with examplesPost-tests were used to assess the children's transfer ability.	Skill set, task distance	Butterfield and Nelson (1991)
Cooperative learning	Detailed description with examples Four tasks (two in the physical science domain and two in the social science domain) were administered. Tasks were isomorphic in the terms of their logical structure.	Interdisciplinarity, skill set, task distance	Zohar (1994)
Analogies	Detailed description with examples Three case-based problems with a common goal were used. The solution to all the problems is to roll a flat object into a tube across an obstacle.	Skill set, task distance	Brown *et al.* (1989)
	Detailed description with examples Representational transfer algorithm called GAMA (Goal-driven Analogical Mapping). The representation mapper finds the correspondences between source and target symbols.	Skill set	Könik *et al.* (2009)

framework has pedagogical and research potential in science education in several aspects. First, it is a tool for designing learning tasks with an emphasis on promoting far transfer skills, which is usually rare in the curriculum. The second aspect is the ability to assess students' improvement in near and far transfer skills (Bell, 2004; Faste and Faste, 2012).

As mentioned in the introduction, in this paper (Part II) we apply this transfer model in science education and demonstrate its value in designing assignments and assessing students' transfer skills. The next section focuses on two studies, one in high school chemistry in a formal school setting and the second in middle school science with an emphasis on physics in an informal setting.

Science education applications

In order to investigate and demonstrate the application of the three-attribute transfer skills framework in practice and research, two empirical studies in chemistry and physics will be presented. The first study – Study 1 – focused on a case-based chemistry approach for high school students who major in chemistry and we assessed the extent of change in students' transfer skills from pre- to post-questionnaires. The second study – Study 2 – focused on an evaluation of ninth grade students' transfer skills, which were developed as part of a physics enrichment academic program. The two studies were chosen for three reasons. First, we wanted to apply purposeful sampling (Forman *et al.*, 2008) to examine as diversified a student population as possible. Therefore, our two studies included formal and informal schooling, and high and middle school students. Second, Study 1 presented an opportunity to assess transfer skills development among learners over the course of a semester or more, while Study 2 explored gender differences between learners who had participated in a short-term enrichment. The third reason is that while multidisciplinary tasks are common in a biology content-rich curriculum, they are less prevalent in chemistry and physics.

Study 1: investigating the applicability of the framework in the CCL learning environment

The Computerized Chemistry Laboratory (CCL) study unit comprises several independent laboratory units containing 13 different computerized experiments. Each unit includes five 45 minute lab sessions and is based on the assumption that students gained the prerequisite chemical knowledge in previous theoretical classes. Each CCL unit starts with a 'real-life chemical story' – a case study concerned with the laboratory's main topic (Dori *et al.*, 2004; Kaberman and Dori, 2009). According to Kobballa and Tippins (2000), case studies feature several themes, including discipline-based teaching and facilitating critical thinking, and they may serve as an assessment tool. Several researchers (Tal and Hochberg, 2003; Dori and Sasson, 2008; Kaberman and Dori, 2009; Sasson and Dori, 2012) applied the case-based method as a science-based teaching and assessment tool, arguing that it helps develop students' higher order thinking skills. Others (Sadler, 2011; Wong *et al.*, 2011) have presented narratives similar to disciplinary-based case studies but have emphasized socio-scientific issues (SSI) while dealing with science-technology-society topics. Both methods are aimed at raising students' and teachers' interest and meaningful learning.

The CCL learning environment integrates the educational elements of case-based and inquiry-based learning along with computer-based real-time data collection and graphing. During the CCL-based inquiry process, students carry out various assignments aimed at expanding their chemical understanding and developing their higher order thinking skills. In particular, students need to understand the chemical phenomena as well as apply and transfer between (move across) the four chemistry understanding levels: (a) the symbol level, which contains formulae, equations and graphs; (b) the macroscopic level, which includes the observable or tangible phenomena; (c) the microscopic or sub-microscopic level, which requires explanations at the particle level (Johnstone, 1991; Gabel and Bunce, 1994; Nakhleh and Krajcik, 1994); and (d) the process level, which is concerned with the way substances react with each other (Dori and Hameiri, 2003; Dori and Kaberman, 2012; Shwartz *et al.*, 2013). The process level usually embodies more than one understanding level and represents the dynamic level of chemical phenomena. Individually, each level of understanding can be imagined as a still picture, whereas process level understanding can be imagined as a movie or video. Being an expert in chemistry requires mastering the skill of applying and moving across the four chemistry understanding levels. These four levels constituted the parameter of skill set attribute (S) in the 3D framework.

Study 1: research goal

The goal of this research was to explore the applicability of the three-attribute transfer skills framework in the design of the transfer assignments as a tool to assess the development in students' skills.

Study 1: setting and participants

The experimental group included about 670 chemistry twelfth grade honor students from 24 high schools in Israel. The chemistry students studied with the CCL program, which includes elements of real-time graphing and hands-on laboratory activities. Each experiment started with a case study, which was used as a motivational tool and matched the subject matter taught in the laboratory activities. Students carried out experiments dealing with topics such as chemical structure and bonding, acids and bases, and energy.

Study 1: method and tools

Since the research was conducted in real-life classrooms, we were faced with limitations that affected the ideal statistical random sample (Rennie, 1998). Such limitations in our study comprised (a) attrition from the pre-questionnaire to the post-questionnaire; and (b) the transfer skill assignments were part of an extended questionnaire (Dori and Sasson, 2008; Kaberman and Dori, 2009) allowing students to choose only part of the assignments. The high school chemical education study was endorsed by the National Superintendent in Chemistry and approved by the Chief Scientist of the Ministry of Education. The Chief Scientist functions as the institutional review board (IRB) for studies conducted in elementary and high schools in Israel.

While the population consisted of students in an honors program (students who chose to study chemistry on an advanced level, similar to AP in the US), they represent a diverse group from a variety of schools, including urban and agricultural, Jewish and Arab, and a wide spectrum of socio-economic statuses. Teachers participated in a week-long CCL summer training program and in an on-going training program throughout the academic year. Since they received support in teaching the CCL study unit, they fully cooperated with the researchers. All teachers had at least 10 years of experience in chemistry teaching and teaching in honors classes (for more details see Sasson and Dori, 2006; Barnea *et al.*, 2010; Dori and Kaberman, 2012).

Pre and post case-based questionnaires were designed to assess a host of thinking skills, including question posing (Kaberman and Dori, 2009), inquiry, modeling (Dori and Kaberman, 2012), graphing (Dori and Sasson, 2008), and near and far transfer. The questionnaires included a variety of assignments for assessing these thinking skills.

To demonstrate our method for designing transfer assignments and assessing transfer skills, we will use the opening paragraph of one of the case studies entitled *"Trees cause air pollution – Is this possible?"* (Dori and Sasson, 2013):

Volatile hydrocarbons are naturally emitted from various types of trees. Isoprene (C_5H_8) is the most common organic compound that oak and sycamore trees emit. Researchers assume that isoprene emission is part of the tree heat protection mechanism. Updated research emphasizes the role of isoprene in the process of smog formation. Due to photochemistry reactions, which involve nitrogen oxides and hydrocarbons, oxidant materials such as ozone (O_3) disperse in air and create the smog effects – haze, inadequate visibility and bad smell.

An example of a far transfer assignment appears below.

Communication between certain animal species is mediated by a group of isoprene-derived hydrocarbons. Describe the special characteristics of these compounds, which enable their transfer from one animal to another through air.

The assignment requires dealing with a new and different learning situation (TD attribute) using several chemical understanding levels (S attribute) and their application in science disciplines like biology, in addition to chemistry (I attribute). Application of various skills, including scientific literacy and reasoning, is needed. Therefore, this assignment calls for three transfer attributes: task distance, TD, interdisciplinary, I, and skill set, S. Fig. 1 presents the profile of this far transfer assignment as point 1 in the cube. All three attributes (TD, I, and S) of this far transfer point in this 3D graph are at their highest values which reflect the high complexity of the learning task.

In the CCL study, the characterization of the far transfer assignment was based on the 3D transfer skills framework using all three attributes, and the students' score calculation was based on two attributes: interdisciplinary – I, and students' ability to apply and move across the four chemistry understanding levels, Skill set – S.

Table 3 Rubric for assessing students' far transfer skill – Study 1

	Applying chemical understanding levels – the skill set attribute – S				Domains – the interdisciplinarity attribute – I
					Number of correct and relevant characteristics
Score	Macroscopic level	Microscopic level	Process level	Chemistry levels' relationship	Chemistry, biology physics or other
0	No use of the macro level or a wrong macro level explanation	No use of the micro level or a wrong micro level explanation	No use of the process level or a wrong process level explanation	No relationship between chemistry understanding levels	Served for discipline content score calculation (1 point for each science domain)
1	Use of one correct characteristic in the macro level	Use of one correct characteristic in the micro level	Use of one correct characteristic in the process level	Partial relationship between chemistry understanding levels	
2	Use of at least two correct characteristics in the macro level	Use of at least two correct characteristics in the micro level	Use of at least two correct characteristics in the process level	Correct relationship between chemistry understanding levels	

Fig. 1 also presents the two other transfer assignments in the physics domains (labeled as points 2 and 3). The two points represent the three-attributes but with different values. The physics assignments are described in detail below (as part of Study 2).

In addition to the characterization of the far transfer assignment in chemistry by the 3D transfer skills framework, we analyzed the content of all responses to the far transfer assignments in the case-based questionnaire using special rubrics that we developed (see Table 3). Based on the content analysis, each student's response to the transfer skill assignments was scored. Since the questionnaire included various assignments with different measurement scales, the scores were normalized on a 0–100 scale which is the common scale among teachers in the educational systems in Israel. Students' scores were based on their use of the four chemistry understanding levels. The rubrics were validated by five chemistry education experts. The five experts also graded 10% of all the students' responses, achieving 90% inter-raters reliability.

We found that in an answer to a case-based assignment, a student can achieve at most three (out of the possible four) chemistry understanding levels. This is due to the difference between an expert and a naïve learner. In this rubric, for each chemistry understanding level, a student can gain 0, 1 or 2 points, setting the maximum chemical understanding level score to 6.

In the far transfer assignment that was described above, the three chemistry understanding levels were macroscopic, microscopic, and process. The only level in which more than 5% of the students gained 2 points was the macroscopic level, while for the microscopic and the process levels, over 95% of the students gained a maximum of 1 point per level. Therefore, we adjusted the maximum chemical understanding levels (S attribute) score to 4 (2 points for the macroscopic level, 1 for the microscopic level, and 1 for the process level).

Calculation of the discipline content score (I attribute) was based on the number of correct science domains—chemistry, biology, and physics—included in the response. The distance between what the students had been exposed to in previous tasks and what the new task called for was high. Therefore, the task was defined as far transfer for all the students and the TD attribute was set as high but was not included in the calculation of the total score.

A student's total far transfer score was calculated as follows:

Far Transfer Score = chemistry understanding levels score + chemistry understanding levels relationship score + disciplinary content score.

Using this scoring method, a student whose answer is presented as Example 1 in Table 4 received a normalized total score of 12.5, as follows: 1 for the macroscopic level, 0 for the microscopic, 0 for the process, and 0 for connecting these chemistry understanding levels. The student who answered example 2 in Table 4 received a normalized total score of 25 – 1 for chemistry understanding levels and 1 for disciplines content.

Study 1: findings – application of the transfer assignment as a tool to assess development of students' transfer skills

Based on the rubric presented in Table 3, the results indicated that the students improved their scores during the Computerized Chemistry Laboratory (CCL) program in far transfer skill (pre mean score was 30.0, $N = 497$; post mean score was 59.0, $N = 525$†). The results showed that, on average, the far transfer skill scores in the post-questionnaire were about two times higher than the ones in the pre-questionnaire. To gain deeper understanding of these results, we analyzed the net gain scores (subtracting the pre-questionnaire from the post-questionnaire scores) sorted by two academic levels—high and low achievers (see also Dori and Sasson, 2008). The net gain of the low academic level students was 35.0 ($N = 79$, $t = 8.90$, $p < 0.0005$) and the net gain of the high academic level students was 28.0 ($N = 175$, $t = 12.80$, $p < 0.0001$).

Table 5 presents the frequency of the chemical understanding levels and the number of science disciplines included in the students' responses.

Table 5 shows that students' far transfer ability can be classified as low and high based on their usage of chemistry understanding levels and science domains—interdisciplinarity.

† The assignments of transfer skills were part of an extended questionnaire and therefore students had the option to respond only to part of the assignments.

Table 4 Students' responses to the far transfer skill assignment, analysis of their content, and scoring – Study 1

Examples	Score in the macro level	Score in the micro level	Score in the process level	Chemistry levels score	Relationship between chemistry levels'	Science disciplines[a] Score	Normalized total score
"The compound should be volatile and in gas state."	1	0	0	1	0	0	12.5
"To make sure the compound will transfer from one animal to another, we have to keep the environment clear of other materials (gases) which can react with it. The compound should be inert."	0	0	1	1	0	1	25
"The compound should be in a gas state in order to be carried in air. The molecular structure should fit the following characteristics: No torsion limiting for the molecules. Low molecular weight so the compound can be carried in air and no reaction with other materials in the air."	2	1	1	4	1	1	75
"The compound should be volatile and of a relatively low boiling temperature in order for it to be in gas state and transfer from one animal to another through air. It must have a special scent that animals can feel in their smell system receptors. It is expected to have Van Der Vaals interactions between its molecules, so I assume those molecules include Carbon (C) and Hydrogen (H) atoms. I think that the compound should not be soluble in water since it might dissolve in rainy conditions."	2	1	0	3	2	2	87.5
"If the compound is transferred from one animal to another through air, I will expect it to be inert and therefore not to react with other materials in the air. The compound should be of low density, less than the air density to avoid sedimentation. The compound should be in gas state, therefore Van Der Vaals interactions exist between these molecules. The compound must fit the receptors' structure in the animal's nose, in order for the animal to smell it."	2	1	1	4	2	3	100

[a] Science disciplines' in this table refers to chemistry, biology, and physics.

Table 5 Distribution of students' use of chemistry understanding levels and science disciplines – Study 1

Students' transfer ability[a]	Chemistry understanding levels	Number of disciplines	Frequency (%) Pre	Frequency (%) Post
Low	None	None	24.4	14.8
	One level	One discipline	45.8	29.9
	One level in one discipline and none in the other		13.4	6.9
	Total		83.6	51.6
High	One level	Two or more disciplines	6.3	8.8
	Two or more levels	One discipline	8.9	26.2
	Two or more levels	Two or more disciplines	1.2	13.4
	Total		16.4	48.4

[a] Low or high transfer ability is based on the researchers' analysis of the responses of the students to the far transfer assignment levels. It reflects level of complexity.

Students were classified as having low transfer ability if they used no more than one chemistry understanding level and one science domain. Students were classified as having high transfer ability if they used either at least two chemistry understanding levels and one science domain or one chemistry understanding level and at least two science domains. The percentage of students classified as having low far transfer ability decreased from 84% in the pre- to 52% in the post-questionnaire, while that of high far transfer ability students increased threefold from 16% to 48%. The dominant discipline students mentioned in their pre-questionnaire was chemistry (50%), while biology and physics together accounted for 25%. In the post-questionnaire, the use of the chemistry domain increased to 64%, while that of the two other disciplines increased to 41%. This increase expresses the progress students made in transferring knowledge from chemistry to other science domains.

Additional analysis revealed that in the pre-questionnaire, the majority (59%) of the students used the macroscopic level to describe the compound characteristics, while microscopic and process based explanations were rare. In the post-questionnaire, there was a 2.5-fold increase compared with the pre-questionnaire in the microscopic and process chemistry understanding levels. The frequency of using the microscopic level increased from 7% to 18% and that of the process level—from 16% to 43%. The decrease in the percentage of expressions of low transfer ability of the students in the post-questionnaire reflects the development of these students' transfer skills.

Study 2: investigating the applicability of the framework in a science enrichment academic program in physics

The Sidney Warren Science Education Center for Youth at Tel-Hai College located in the northern part of Israel is an academic science center. It is aimed at strengthening the potential of middle and high school students in order to encourage them to pursue higher education, with an emphasis on science and technology studies. Activities taking place in academic and research laboratories with varied programs include in-depth processes that strengthen scientific thinking skills as well as short-term enrichment activities. Curriculum development is based on the constructivist approach, which views learning as an active process that constructs meanings in the mind of the learner. Learning environments based on this approach have been found to be particularly beneficial to students because they enhance their learning processes (Von Glasersfeld, 1991; Rivet and Krajcik, 2004; Rosenfeld and Rosenfeld, 2006; Dori and Sasson, 2008).

The science enrichment academic program, as an informal learning environment, provides valuable motivational opportunities for students to learn science. These environments can have an impact on learning while addressing aspects of science education that might be missing in more formal, class-based science learning environments (Bozdoğan and Yalcın, 2009).

As part of an internal assessment process for effective science interventions by the Sidney Warren Science Education Center for Youth activities, an evaluation of the science enrichment academic program was conducted. Students attend this program on a voluntary basis and are not obliged to respond to the questionnaires. The institutional review board (IRB) of Tel-Hai College reviewed the research plan and tool and approved the study. Students' attitudes toward physics knowledge, conceptions of physical concepts and their transfer skills were investigated.

Science skills have been associated with gender differences (Linn and Pulos, 1983). Girls' experiences in science and math differ from those of boys throughout their lives, causing lack of confidence among girls (Linn, 1980a, 1980b). Starting at an early age, girls display little interest in physics compared to boys (Hoffmann, 2002). Due to these gender gaps, special interest was given to identifying differences between genders in order to design an effective intervention aimed at narrowing the gap between boys and girls in physics performance. Results were used for the improvement of the instructional design of the physics activities (Sasson and Cohen, 2013). The gender differences were emphasized in Study 2 because middle school students are expected at this stage to decide on their major in a science domain or in another domain. This career choice is gender dependent. In Study 2 we analyzed the transfer assignments based on the three transfer attributes framework (similar to Study 1).

Study 2: research goal

The goal of Study 2 was to evaluate the transfer skills of ninth grade students who participated in an enrichment program and compare differences between boys and girls.

Study 2: setting and participants

The physics lab-oriented enrichment day focused on pressure in fluids and included three short activities which involved experiments on flotation and water pressure conducted by groups of two or three students. Between the activities, students watched several demonstrations, some given by a laboratory assistant, and others through films and PowerPoint presentations. These were accompanied by discussions and questions closely related to the experiments that followed. The day ended with an activity involving construction of simple toy steamboats (called putt–putt boats, due to the noise they create when vapor is emitted into the water). There was also a competition to test the boats' performance. Three or four instructors worked with each group of students (about 25 students in each group) one of them, an academic expert in physics, led the science activity while the others served as assistants. Most of the physics experts were males while most of the assistants were females. Fifty ninth grade students (ages 14–15) from two high schools in the Upper Galilee in northern Israel were examined.

Study 2: method and tools

The questionnaire, aimed at assessing knowledge and concepts of air and water pressure, was comprised of assignments based on Clough and Driver (1986), and Flores and Gallegos (1998). The assignments included both open-ended questions requiring explanation and multiple-choice questions. The answers of the open-ended questions were graded on a scale of 0–2, where 0 meant "wrong answer," 2 meant "correct answer," and 1 meant "partially correct answer" (Sasson and Cohen, 2013).

Fig. 2 presents one example of the near transfer assignments that were used in the questionnaire. The assignments dealt with how differences in air pressure affect the water level in a U-shaped tube. Students were asked to imagine a U-shaped tube filled partially with water. One side of the tube was closed with a cork. Water was added to the other side, and then the system was allowed to reach equilibrium. The question asked which side of the tube had the higher water level. We marked an answer correct (scored 2) if the student took into account the pressure of the trapped air in the closed side of the tube. A partially correct answer (scored 1) stated that air is incompressible and therefore acts as a rigid barrier.

Referring to our three transfer attributes framework, the question was defined as near transfer. Although it required knowledge and application of physical understanding, the students in Study 2 had not learned these subjects earlier as part of their school curriculum. It was not similar to assignments the students had previously encountered, and therefore we defined task distance – TD as high. Students were required to explain their responses based on physical principles. Since the assignment was based on one discipline and did not require special skills, the attributes interdisciplinarity (I) and skill set (S) are low. This assignment is represented in Fig. 1 as point 2.

This point shows that the near transfer assignment in the physics domain (labeled as point 2) has a different location on the 3D graph than the other far transfer assignments. In the near transfer assignment two of the three attribute values (I and S) are low while the TD is high.

The far transfer assignment in physics (see below) demonstrated the application of the three transfer attributes:

Heart beats cause the blood to flow inside our body. During heartbeats, the heart contracts and then relaxes. When the heart contracts, will the blood flow into it or out of it? Please explain how the blood flow is connected to pressure.

Students were asked in this assignment to describe how the heartbeat causes blood to flow in and out of the heart. This required them to apply a principle from physics to a different discipline, biology, in a completely new situation, and to identify the correct connections between processes. Hence, this assignment features a high degree in all three transfer framework attributes (TD, I, and S). This assignment is represented as point 3 in the cube framework (see Fig. 1).

In the rubric for this far transfer assignment, we marked an answer correct when it mentioned the core scientific principle that blood flows from high pressure to low pressure. Table 6 presents some examples of students' answers to the near and far transfer assignments and their scoring.

Study 2: findings – application of the transfer assignment as a tool to assess gender gaps

Table 7 presents students' results. Findings indicate that the boys had a significant advantage in near transfer skill in comparison to the girls, but no significant differences between boys and girls were found in far transfer skill.

A U-shaped glass tube is filled with water. Initially, the water level is the same in both sides. One side is closed with a cork. Water is added through the open side. Then we wait until the water is still. What will be the water level on both sides then?

a. The water level will be the same in both sides
b. The water level in the open side will be higher
c. The water level in the closed side will be higher
d. The water level in the closed side will remain as before.
e. The water level in the open side will be higher
Please explain your answer.

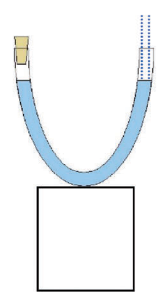

Fig. 2 An example of a near transfer assignment in physics – Study 2.

Table 6 Examples of students' answers in the near & far transfer assignments – Study 2

Question type	Wrong answer (0)	Partially correct answer (1)	Correct answer (2)
Near transfer	"Because the law of connected vessels says the water is equal everywhere."	"Because on the closed side, the water has no place to go because there is water there."	"Because on the closed side, the air pressure is higher and on the open side, the air can get out."
Far transfer	"The contraction applies a vacuum pressure to the blood and the blood is attracted to it."	"Because of the pressure, the blood flows in the arteries."	"When the heart is relaxed, the pressure inside is lower and the blood is free to get inside. When it contracts, the pressure grows and the blood flows away."

Table 7 Students' near & far transfer skills results – boys vs. girls– Study 2

	Girls N = 30		Boys N = 20		
Question type	Mean (min = 0, max = 2)	S.D	Mean (min = 0, max = 2)	S.D	t test
Near transfer	0.34	0.66	0.78	0.77	$t = -0.44$ $p < 0.05$
Far transfer	0.12	0.31	0.41	0.61	n.s.

n.s. = non significant.

In the science enrichment academic program in physics the 3D transfer skills framework was used to characterize the near and far transfer assignments. The three-attributes formed the criteria for assessing students' responses.

Discussion

With the proliferation of the knowledge economy and the rapidly changing requirements from graduates, learning is now considered to be a lifelong process. Transfer is essential for lifelong education and learning. Educational institutions and workplaces are increasingly concerned about a student's or a worker's transfer abilities, and therefore study professional transferable skills (Dall'Alba and Sandberg, 2006; Tigchelaar *et al.*, 2010). Feltovich *et al.* (1993) claimed that deficiencies in the learning of complex material are of three types: (a) incorrect or naïve knowledge – misconceptions, (b) inert knowledge – transfer inability or inability to flexibly apply knowledge in new situations, and (c) lost knowledge – or the lack of retention. Lobato (2006) claimed that researchers' progress in understanding and supporting the generalization of learning has been limited due to methodological and theoretical issues associated with transfer. In the context of learning processes, understanding the relationship between transfer theory and its practice is of great importance. Rebello *et al.* (2007) and Rebello and colleagues (2005) identified and characterized transfer as it occurs in an interview. They suggested a dynamic transfer model that is mediated by target tools from the external inputs and source tools activated from long-term memory. Cognitive processes are mediated through higher-order control by epistemic meta-tools.

The purpose of this paper was to present applications of the three-attribute transfer skills framework. Our 3D framework provides a practical tool that combines the three stages for developing transfer skills as presented by Cornford (1991). The acquisition of the basic skill, the development of the generalized application, and transfer of the generalized skill to a different setting or domain. We used two empirical examples to demonstrate the potential of the framework in designing near and far transfer assignments. We also presented the use of these tasks as an assessment tool to evaluate students' development in transfer skills and differences between genders. Applicability of the framework was found in both studies (1 and 2).

Several studies have indicated that curriculum and teacher behavior, influenced by traditional gender stereotyping, affect girls' interest in science (Kelly, 1987; Häussler and Hoffmann, 2002). Far transfer tasks are still relatively rare in educational studies, and we assume that the gaps that usually exist between boys and girls have not as yet been investigated in studies emphasizing this skill.

Complex learning involves the integration of knowledge, skills, and the transfer of what students have learned in one domain or situation to the new one and to daily life. Routine tasks that require an algorithm solution are no longer enough. Complex cognitive tasks are becoming increasingly important. Learning assignments that call for problem solving, reasoning, creativity and transfer can promote students' ability to flexibly adjust to rapid changes in their learning environment. Educators are called upon to design and develop complex curriculum assignments. Design theory and its practice requires the development of teacher professional development and training programs. The 3D transfer framework demonstrated in this article is a pedagogical tool for developing and characterizing transfer assignments. Explicit teaching of the transfer framework in teachers' and educators' programs may affect the development of transfer skills among their students and promote better or more meaningful learning. This explicit instruction, using the 3D transfer framework proposed by us, may increase awareness among learners and educators similar to the discussion by Yelon (1992) and his learning model for achieving transfer. In addition, the three-attributes (I, S, and TD) constitute the basic criteria for students' assessment and therefore, the 3D framework has value in the assessment of transfer skills.

As demonstrated in the example of the chemistry domain assignment, the four chemistry understanding levels were integrated into the transfer assessment model (S attribute) while in both studies the examples included a variety of domains (I attribute), thereby creating a powerful tool for assessing near and far transfer assignments. Similar to our study in chemistry and science, Schönborn and Bögeholz (2009) investigated translation between different external representations in biology. They explored experts' views on the nature and role of transfer and translation and found that translation in biology requires moving across more than one external representation that delivers the same biological idea or different biological ideas. Understanding can be fostered by supporting linking and integration of information from multiple representations, topics, and domains. These two examples, in chemistry and biology, emphasize one of Eraut (2004) cognitive variables that refer to the nature of 'what is being transferred'. The variables that he suggested (as shown in Table 1) are important aspects of transfer.

We call upon science educators from all the sciences to cooperate in order to develop and define specific scientific principles for each domain. These principles will enable all of us to connect abstract and concrete levels (as is common in physics and math), to link organization or chemistry understanding levels (as used in biology and chemistry) and to combine the microscopic and the macroscopic levels defined in general science courses. Cooperation between experts in the science domains is most crucial in designing far transfer assignments when the interdisciplinary attribute has a high value in our framework.

To summarize the possible contributions for the science education community, here are some explicit insights and implications of the 3D framework:

• The 3D framework may serve as a tool to support deep theoretical understanding of the different dimensions of transfer skills.

• Using the 3D framework as a tool to mediate between theory and practice, the framework provides a unique interface between researchers and teachers in science education.

• Teachers may become (a) 'experts' by serving as designers of learning environments (rather than just using the information from the textbook) and by producing their own transfer assignments, (b) 'action researchers' who track and are aware of the relationships between their pedagogical choices and their students' learning outcomes.

Further research is needed and we recommend designing studies which will investigate questions such as (1) Are the three attributes equal in terms of determining transfer difficulty? (2) How can we systematically design assignments with increasing levels of transfer difficulty for each attribute? (3) How is transfer related to cognitive load novelty and creativity? (4) How can we assess the contribution of applying this framework to improving transfer in science classrooms?

Finally, we suggest that the question of transfer should be analyzed using the three dimensions of similarities and differences between the new learning task and the reference task, the number of science disciplines or sub-disciplines integrated in the learning situation, and the set of skills that are acquired or developed through learning, training, or experience. Instructional designers of learning environments and teachers can use the model to form and assess special learning assignments in order to develop students' transfer skills. As presented in this paper, researchers can also use the same model to investigate educational intervention effectiveness. Both parts – the review (Part I) and the research (Part II) – contribute to narrowing the gap between the theory of transfer, empirical research, and the practice of transfer in science classrooms.

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