Research Article

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Development and validation of customized pedagogical kits for high-school chemistry teaching and learning: the redox reaction example

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Abstract: In this paper, we describe the structure, development, and validation process of customized pedagogical kits (CPKs) for differentiated instruction (DI) in chemistry. The CPKs rely on the DI approach, comprising varied pedagogical activities (e.g., games, inquiry activities, puzzles, simulations, models) designed as treatments, to help chemistry teachers personalize their teaching according to students' misconceptions. The kits are based on the response to intervention (RTI) model, where the teacher applies an ongoing evaluation to meet the individual student's needs within an evolutionary flexible process of learning. Each kit includes a diagnostic task, its characterization, pedagogical treatments for diagnosed misconceptions, and an assessment task, to evaluate the effectiveness of the treatments implemented in the classroom. The kits are developed along relevant literature criteria for using DI strategies and are based on constant validation and ongoing assessment, as demonstrated in the Redox-reaction CPK development. The validation and impact of the CPK on students' achievements are supported by 25 chemistry teachers that implemented the full kit in their classrooms. Furthermore, the CPKs developed in the present research have succeeded in resolving many of the difficulties and challenges mentioned in the literature as obstructing the implementation of DI.

Keywords: chemistry education; development; diagnostic tasks; differentiated instruction; formative assessment; response to intervention (RTI).

Introduction

Chemistry is known to be difficult to learn and teach because it comprises abstract theoretical concepts that require the learner to understand and make associations on both the macroscopic and microscopic levels, while using symbols (Dori & Hameiri, 2003; Johnstone, 1991). Many teachers adhere to traditional instruction methods, mostly frontal lectures (Blonder & Mamlok-Naaman, 2019). Teachers also lack the ability, qualification, and skills to monitor intensively and closely, in real time, the state of their students' learning in crowded heterogenic classrooms (Tomlinson, 1995). Chemistry classes are normally heterogeneous, with deep gaps between different students' learning profiles, interests, previous knowledge, social background, self-efficacy, perception of chemistry, views about studying it (Matuk, Linn & Eylon, 2015), aptness, and personal learning pace (Heacox, 2002). To complicate matters further, quite a few students hold misconceptions that are liable to hinder their understanding and learning of chemistry (Ausubel, 1978), and may yield incorrect views

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and ideas. For instance, abstract ideas such as ideas about a particular nature of matter are not readily used to answer questions about the properties of matter. Students hold perceptions about the nature of matter, imagining it to be a indivisible mass rather than particle aggregate (Kind, 2004), because they are comfortable with these ideas that are supported by their senses (e.g., seeing, touching). As Millar (1989) suggested, “children do not need to use particle ideas because their own theory of matter has worked perfectly well for them. This has implications for influencing change in students’ ideas” (Millar, 1989 in Kind, 2004, p. 6).

Having thoroughly considered the above difficulties, we suggest that advance consideration of student misconceptions while teaching and learning chemistry, is likely to help improve students’ understanding and achievements.

Addressing student misconceptions by applying pedagogical treatments, along with a differentiated instruction (DI) approach, will probably lead to proper teaching and learning processes, especially within a heterogeneous classroom, and eventually advance and foster social integration. The result is an educational and social stance that encourages diverse students to learn and attain better achievements (Aviran, Easa, Livne, & Blonder, 2020; Baumann & Melle, 2019; Fink, 2005; Good, 2001; Kieserling & Melle, 2019; Lawrence-Brown, 2004; Vaughn, Bos, & Schumm, 2000).

Treating each student misconception with several customized and different pedagogical methods and activities, followed by evaluation of the process and the outcomes of students, are based on the educational approach “Response to Intervention” (RTI). The RTI approach, initially used in special education, sets out from the students’ individual learning situation (Benny & Blonder, 2016; Hess & Kelly, 2007; Madaus & Shaw, 2006).

This article describes in detail the process of development and validation of Customized Pedagogical Kits (CPKs) in chemistry devised to treat specific misconceptions that high school students hold, revealed by a diagnostic task. These pedagogical treatments include differentiated instruction strategies (Tomlinson, 2003).

Theoretical framework

Challenges of chemistry learning

Because chemistry concepts and phenomena are generally related to or based on the abstract sub-micro level, chemistry proves a difficult subject for many students (Johnstone, 1991). Chemistry curricula commonly incorporate many abstract concepts, which are central to further learning in both chemistry and other sciences (Taber, 2002). The abstract nature of chemistry along with other content learning difficulties (e.g., the mathematical nature of much chemistry, visuospatial thinking) means that chemistry classes must have a high-level skill set (Kiernan, Manches, & Seery, 2021; Taber, 2002; Zoller, 1990), and require the learner to understand and make associations on both the macroscopic and microscopic levels, while using symbols (De Jong et al., 2012; Dori & Hameiri, 2003; Johnstone, 1991). Furthermore, many teachers adhere to traditional instruction methods (mostly frontal lectures) (Blonder & Mamlok-Naaman, 2019). Teachers lack the ability, qualification, and skills for intensive, close, real time monitoring of the state of their students’ learning in crowded classrooms (Tomlinson, 1995). In addition, in most cases chemistry classes are heterogeneous, with deep gaps between different students’ learning profiles, interests, previous knowledge, social background, self-efficacy, perception of chemistry, views about studying it (Matuk, Linn, & Eylon, 2015), aptness, and personal learning pace (Heacox, 2002). To complicate matters further, quite a few students hold misconceptions (or naive conceptions, preconceptions) that risk hindering their understanding and learning chemistry (Ausubel, 1978).

Diagnosing misconceptions in chemistry

The educational psychologist David Ausubel (Ausubel & Youssef, 1963) noted that students are not *tabula rasa* when they start their learning process but have perceptions and misconceptions that significantly affect

learning. According to Ausubel (1978), if a person possesses an appropriate conceptual and content knowledge, that person would successfully assimilate new knowledge. However, inappropriate previous knowledge is liable to hinder learning. Ausubel termed that inappropriate knowledge as “misconceptions”, which he saw as crucial, being extremely persistent and resistant to change. Other researchers (Garnett, Garnett, & Treagust, 1990; Garnett & Treagust, 1992; Zoller, 1990), confirmed that misconceptions concern almost every topic of chemistry learning.

Kind, as other researchers (Brook, Briggs, & Driver 1984; Stavy, 1990a) indicated that misconceptions affect students’ thinking and views, and lead them to incorrect ideas about science and chemistry: “Children’s naive view of matter, acquired through long experience from childhood, is sufficiently strong to be difficult to relinquish and inhibits consistent thinking about matter. So, although children may have the necessary skills to answer correctly questions about matter which require logical or abstract thought, their naive view leads them to incorrect ideas” (Kind, 2004, p 8).

This understanding spurred us to identify students’ misconceptions and develop treatments for them, to overcome these barriers and support the learning process.

In the present paper we utilize the topic of reduction-oxidation reactions to illustrate our approach. Numerous studies have dealt with difficulties related to oxidation-reduction reactions, specifically the definition of oxidation-reduction and its balancing. Schmidt and Volke (2003) argued that those difficulties are caused by students’ misconception that the oxidation state is equal to the overall charge of reactants. Garnett, Garnett, & Hackling 1995, p. 84 list additional misconceptions and misunderstandings of students regarding oxidation–reduction:

- (1) The oxidation number of an element is the same as the charge of the monatomic ion of the element.
- (2) Polyatomic species can be assigned an oxidation number and this equals the charge of the species.
- (3) In all chemical equations, the “addition” and “removal” of oxygen and hydrogen can be used to identify oxidation and reduction.
- (4) In all chemical equations the change in the charges of polyatomic species can be used to identify oxidation and reduction.
- (5) Oxidation and reduction processes can occur independently of each other.

Chemistry teachers at all levels aim to make the subject accessible to an extent that allows for maximum meaningful learning. To achieve this, teachers should take into account concepts/misconceptions already held by students while teaching redox reactions; in other words, teachers should be able to diagnose students’ misconceptions.

The literature describes a number of tools that serve to diagnose difficulties in understanding and students’ misconceptions. First among them are personal interviews with students (Osborne & Gilbert, 1980; Watts & Zylbersztajn, 1981). Another tool involves multiple-choice exams (Tamir, 1971), such as a questionnaire (Linke & Venz, 1978) that detects students’ misconceptions regarding chemistry concepts. A third tool is that of diagnostic questionnaires developed as part of a research investigating students’ difficulties in a particular topic. Such questionnaires may be single-layered, i.e., without explanations, or multi-layered, with explanations. The questionnaires consist of multiple-choice questions with distractors based on students’ misconceptions (Garnett, Garnett, & Hackling 1995). The research literature therefore regards diagnostic questionnaires as an effective means to assess the knowledge of students and detect their misconceptions in relevant content topics (Treagust, 1988).

Whereas the literature is packed with papers providing evidence of misconceptions, fewer papers suggest potential treatments. The current article describes treatments developed over the present research to address students’ misconceptions in chemistry redox reactions. It also provides evidence of the treatments’ effect on the students’ achievements.

Differentiated instruction (DI) meets students' misconceptions

Differentiated instruction (DI) is a two-stage process that begins with diagnosis and dynamic assessment of the students and the classroom environment, followed by designing and integrating instruction approaches and strategies that meet the students' needs based on the findings of the diagnosis stage (Heacox, 2002). Walpole and McKenna (2007) claim that high-quality DI is vital in a large age group, and should be followed by adjusted teaching in small diagnosed groups. They suggest that intensive individual intervention should come last if needed.

Tomlinson (1999) maintains that in an improved/enhanced education system, practical implementation of DI would require making changes that would allow children to study with children from other age groups. The DI concept evokes the past single all-age classroom, where students of different ages used to study together, each at his or her own pace and ability, rather than attending classes arranged by age. This idea requires adjusting the teaching to diverse individual abilities, namely, teaching the syllabus in different ways (Hess & Kelly, 2007). DI enables teachers to cope with the diversity of their students when they set out to achieve educational, social, and personal goals.

According to Bundoc (2007), a growing population diversity and the emergence of larger classes, which are liable to undermine the students' achievements, underlie the rationale of DI implementation. Tomlinson (2003) explains that the growing diversity within the classes has obliged educators to devise new ways to meet the students' needs. This diversity concerns different student variables, such as: cognitive abilities (namely, multiple intelligence levels and different IQ's), learning styles, socio-economic factors, readiness, learning pace, gender effects, and cultural effects (Heacox, 2002). Tomlinson (2003) mentions additional factors that made schools rethink their teaching methods. First among them is the achievement gap between students from different cultures. The second factor is the growing tendency of integrating students with special needs into the school (inclusion). The third factor that encouraged diagnostics and DI was the growing number of non-native speakers in the classroom. Finally, she identified a weakness in the handling of outstandingly gifted students. Colangelo, Assouline, & Gross (2004) and Benny & Blonder (2016) substantiate the significance of all these factors. Their studies indicate that strengthening all the students, including gifted ones, is the key to the school's success. According to the DI approach, students in a heterogeneous class can progress if the learning environment is compatible with their needs. To ensure such compatibility there is a need for ongoing diagnosis, adjustment, and monitoring of classroom learning by adapting the teaching mode to the learner's characteristics (e.g., structured vs. flexible teaching or deductive vs. inductive teaching). These measures also enables adapting the learning framework (individual, small group, or full classroom) and the extent of the teacher's involvement in the learning process (Corno & Snow, 1986).

In this study, several treatments are developed alongside differentiated instruction strategies and customized to address each diagnosed misconception or difficulty. The teachers later adapt them in class to the students' profiles. The implementation of the treatments comprised in the CPK, follows the "Response to Intervention" (RTI) approach inspired by special education (see Figure 1).

Figure 1: Stages of the RTI model in the current study according to the teaching sequence.

Response to intervention (RTI) model

When a student struggles with the regular curriculum, the first reaction of most schools is to refer that student to special education testing. Traditionally, schools have concluded that “a student’s lack of success in the regular education system means that he must have a disability” (Prasse, 2009). However, special education testing rarely evaluates the quality and effectiveness of the teaching method in that student’s class. The RTI approach addresses the problem from an opposite perspective. It assumes that if a student is struggling, the teaching he or she receives is faulty, and seeks better ways to meet the specific learning needs of that student, waiting for the schools to make the required conceptual switch.

RTI is a comprehensive approach that focuses on early preventive intervention. This educational model is designed to effectively support students who experience learning difficulties, and is often used in special-needs education. RTI offers support adjusted to the student’s needs and progress. It tests and evaluates the student on an ongoing basis over a multi-stage intervention. The assumption behind this method is that controlled methodical support will prevent failure experiences and a sense of low self-efficacy. A school or a teacher adopting this approach would go through the following stages: identifying a student with suspected learning difficulties (diagnosis stage), differentiated instruction, progress monitoring, and adjustments whose type and intensity depend on the student’s reaction to the intervention. After the initial diagnosis process, a personalized intervention is devised for each student (Lipka & Siegel, 2012). Next comes identifying students who do not benefit from the intervention, namely, those who continue to lag behind their classmates despite the adjusted support they received. These students are referred to an external special educational framework that suits them (Madaus & Shaw, 2006; Speece & Case, 2001).

In the present study, the differentiated instruction approach served as a basis for developing pedagogical treatments tailored to students’ misconceptions. These misconceptions are the third component of CPKs, and represent in this study the third stage of the RTI model (see Figure 1).

We focus on the cognitive characteristic of learners that leads to misconceptions in chemistry as revealed in diagnostic tasks designed to detect those misconceptions. The trigger for our study was previous research indicating that addressing students’ misconceptions by using DI strategies adapted to the needs and learning styles of the students has improved their understanding and promoted better learning (Corno & Snow, 1986) (Figure 2).

Principles underlying the CPK design

Several basic principles underlie the developed CPKs’ design and validation process:

- (1) The CPKs address subject matter included in the high school chemistry curriculum.
- (2) They diagnose misconceptions and central difficulties in learning the concept they address.
- (3) They handle specific misconceptions detected in the diagnostic task.
- (4) They undergo systematic validation of their diagnostic power and their effectiveness in addressing the diagnosed misconceptions.

Figure 2: The components of the CPKs for DI in chemistry.

- (5) They represent a non-standard approach to remedial teaching, incorporating varied DI strategies and not only worksheets, evaluation sheets, exercises or quizzes. They also underscore the importance of teacher awareness of the differences between students, and therefore comprise a variety of activities for teachers and students alike.
- (6) They offer the teachers materials and explanations they can incorporate in their teaching. To achieve this, the kits comprise clear instructions for students and didactic tips and recommendations for teachers regarding ways and options for implementation and teaching in class and for specific activities that address misconceptions.

Research methods

The present study is a mix-method one, mainly based on quantitative research tools and data collecting, including close-ended questionnaires for teachers and students, diagnostic tasks, and student evaluation tasks. It also used qualitative tools, such as teacher and student interviews that this article does not analyze as they do not support directly its stated purpose of describing the development of CPKs and their contribution to correcting misconceptions in Chemistry.

Research questions

The following research questions served as our guidelines:

- (1) What are the main aspects of the CPK development and validation processes?
- (2) What main effects did the pedagogical treatments suggested in the redox CPK have on students?
- (3) What challenges, frequently mentioned in the literature as hindering DI, do the CPKs developed in the present study address?

Research population

To ensure an ongoing evaluation of the CPK development process, different groups tested each development stage, playing different roles in the process (see table).

The development team

This group comprised the authors, all science education researchers, highly experienced high school chemistry teachers (over 15 years of teaching experience), former tutors and chemistry teacher leaders ($N = 10$).

Teacher leaders

A group of experienced high-school chemistry teachers, who led regional professional learning communities (PLC) of high school chemistry teachers, thus promoting the professional development of their colleagues ($N = 18$) (Blonder & Waldman, 2019; Waldman & Blonder, 2020).

Experimental implementation teachers

In-service high-school chemistry teachers who completed a professional development course on differentiated instruction in chemistry. They implemented the diagnostic tasks and the CPKs in their chemistry classes in different schools throughout Israel ($N = 25$).

High school students

All the students who participated in the experimental implementation of the CPKs. Their performances ultimately substantiated the validity of the entire development process ($N = 327$).

Conceptual framework

The development protocol of the kits includes predetermined criteria.

Development of the diagnostic tasks

These tasks may comprise single-layered multiple-choice questions (without explanation), multi-layered multiple-choice questions (with explanation) (Kaltakçı, 2012; Peşman & Eryılmaz, 2010), and dichotomous (yes/no) questions (Downing, 2006). The criteria we used to develop the diagnostic questions included distractors that generated misconceptions described in the relevant literature or ones that emerged in an experimental pilot study conducted in high school chemistry classes by the teachers. The questions were specific, checking up to two elements or factors at a time (Treagust, 1988).

Development of the DI pedagogical treatments

The pedagogical treatments which we suggested for each student misconception represented diverse strategies of teaching. These DI treatments corresponded to the misconceptions to face each group of students with a misconception that emerged in the diagnostic task, and help them achieve appropriate and significant understanding (Tomlinson et al., 1993). The diverse strategies used in the treatments responded to the students' different profiles. Such strategies combined technology (Barak, 2007; Barnea, 2000; Barnea, Dori, & Hofstein, 2010; Hawkins & Phelps, 2013), creativity, response to various learning styles (Blonder & Sakhnini, 2012) response to varied intelligence levels (Gardner, 2011) and grouping according to common characteristics, game-based learning (GBL). The use of varied strategies facilitates responses catering to different students in the class so that students having misconceptions receive responses that address their misconceptions. Students who reply correctly to the diagnostic task questions, showing that they hold the accepted scientific conceptions, are offered responses that challenge them, deepening and expanding their knowledge.

Development of evaluation tasks following the completion of the customized pedagogical treatments

The evaluation tasks correspond to the preliminary diagnostic tasks in terms of structure, type, scope, length, content, and requirements. They check the effectiveness of the customized activities that had addressed the discovered misconceptions and detect eventual changes in the students' misconceptions and learning achievements. The evaluation task allows the teacher to test and evaluate the students' understanding. If the previous misconceptions have disappeared, the teacher goes on with the planned curriculum. If some students still hold the same misconceptions, the teacher refers them to individual tutoring sessions.

CPK development: evaluation and validation

For the CPKs to achieve the purpose of helping high school children overcome misconceptions in chemistry, they undergo meticulous evaluation and validation over a 9-stage development process conducted by the development team (Figure 3).

CPKs development model

Figure 3: CPKs nine-stage development model

Stage 1: A CPK is conceived as an idea that follows the detection of misconceptions and difficulties encountered by chemistry students in understanding curricular content. The development team map these difficulties, analyze students' answers in chemistry matriculation exams, and review academic literature dealing with misconceptions in chemistry (e.g., Kind, 2004).

Stage 2: The team scans an existing inventory of diagnostic tasks and the literature for a task that addresses the specific detected problem. Once a suitable task is found, it becomes the basis for a CPK development. If no suitable task is available, the development team puts together a diagnostic task that becomes the basis for the development of the required CPK.

Stage 3: The full development team discusses the diagnostic task. They examine and adjust it to the local language, edit it, and verify that it follows the criteria listed above (Pappa & Tsaparlis, 2011; Treagust, 1988).

Stage 4: Several in-service teachers (from the experimental implementation group) receive the diagnostic task for trial in their classes and bring their students' results back to the development team. The development team uses the collected findings to make improvements in the task. The changes made at this stage aim, among other things, to ensure the clarity of the tasks and the distractors. The incidence of distractors (usually based on common misconceptions) in the students' answers is rechecked, followed by omission or addition of certain ones. The issue of whether or not students must explain their choice of a certain answer is decided next.

Stage 5: The experimental implementation teachers go over the improved version of the task and submit additional comments to the development team. The development team collects their comments, doubts, improvements, and observations. This is the second layer of the diagnostic task's improvement. An in-depth discussion follows the diagnostic task's characterization: its timeframe, delivery

mode (online or otherwise), further elucidation of the misconceptions the task is expected to detect, and exploration of their origin. Finally, tips are prepared for the teacher who delivers the task in class, and a scoring rubric is proposed to evaluate the students' achievements in the diagnostic task.

Stage 6: One team member develops a first version of pedagogical treatments for the misconceptions detected in the task. This stage usually takes 2–3 months. Significantly, the team develops simultaneously several CPKs on different topics.

Stage 7: Expert validation of the CPK content. The development team head calls a meeting of the whole team for a test-run of the CPK under development. The team member who developed the different treatments chairs the meeting. The development team members actively try the kit, simulating students at the different DI stations. Over the experience, the development team-members note down their findings, comments, and suggestions, which are then collected and discussed. Following this session, the team member in charge of the CPK development further improves it.

Stage 8: External content validation. The complete kit with the diagnostic task and treatments for various misconceptions is retested in chemistry teachers' summer courses offered by the development team on DI and chemistry teaching in heterogeneous classrooms. The participating teachers' findings, suggestions, and comments serve to make additional improvement to the kit.

Stage 9: External structure and content validation. Several experimental implementation teachers implement the kit in their classes. The first author accompanies the teachers during the pilot implementation. The researchers collect the findings and present them to the development team members for further improvement of the kit. At this stage, the changes seek to further clarify the instructions, improve the treatments' effectiveness, verify that DI strategies are properly represented in the treatments, add or omit secondary activities, and reconsider whether or not to ask students for explanations at the diagnostic stage of the CPK. After this stage, the kit undergoes final graphic design and becomes available to all the chemistry teachers via an open-access website.

Results

In the results section, we illustrate the development process of the CPK using the Redox reaction. We describe how each stage was applied to the Redox CPK, the development considerations, and relevant evidence from teachers and students.

Stage 1: Choosing the CPK topic (The example of Redox reactions).

Development considerations

Two main considerations underlay our decision to develop a CPK that focuses on electron transfer between the reducing agent and the oxidizing agent: Reported teachers' difficulties in explaining this topic in class, and analysis of students' answers in the National Matriculation Exams in chemistry.

The idea of creating a CPK on oxidation-reduction originated from the chemistry teachers in the development team, who came across students' misconceptions on this topic in class and analysis of students' exam answers. Probing students' misconceptions and their sources, the researchers noted that students misunderstood and confused between concepts such as oxidizing agent and reducing agent, oxidation product and reduction product. A major misconception concerned the transfer of electrons in oxidation-reduction processes: students thought that electrons transfer from the reactant to the product and not between reactants, missing a basic rule in a chemical reaction.

Stage 2: Scanning existing diagnostic tasks.

The development team head scanned the inventory of previously developed diagnostic tasks, and found one that examined redox concepts and misconceptions. It was composed of six statements organized in a table

(Appendix A). The students had to decide whether each statement is true or false and correct the wrong statements. They also had to choose one wrong statement and explain the error that makes it wrong. This diagnostic task was adopted and further adjusted.

Stage 3: Adjusting an existing diagnostic task.

The entire development forum inspected the proposed diagnostic task in detail, adjusting it to the misconceptions that had to be addressed (Kind, 2004). The adjusted diagnostic task was also designed to reveal whether the errors originated in a misunderstanding or a previous misconception, hence, it contained two layers of diagnostics, a first layer of true-false statements, and a second layer of the reasoning behind the incorrect statement. The coupling of the two layers was likely to determine whether the source of the students' error was a misconception or a misunderstanding of the material being studied (Treagust, 1988) (see Appendix A, Q1, Q2). Table 1 presents and explains the misconceptions and difficulties that students encounter in learning the topic of oxidation-reduction that the diagnostic task aims to identify.

Stage 4: Trial run of the diagnostic task.

A group of experimental implementation teachers ran the diagnostic task with their students in 25 chemistry classrooms, and collected the students' answers. They reported that 327 students countrywide completed the diagnostic task within 15–20 min. The development team received the students' answers with the observations, comments, and suggestions of the classroom teachers. Analysis of the answers revealed that all the expected misconceptions and difficulties actually emerged in the different classes. The diagnostic task therefore remained as it was without further change.

Table 1: Misconceptions and difficulties detected in the diagnostic task.

Reaction: $\text{Cl}_{2(g)} + 2\text{Br}^{-}_{(aq)} \rightarrow \text{Br}_{2(l)} + 2\text{Cl}^{-}_{(aq)}$		
Students are asked to read the statement in the content column and answer whether or not it is correct for the above reaction.		
Question No.	Content	Detected difficulty/misconception
A	Electrons transfer from $\text{Br}^{-}_{(aq)}$ to $\text{Cl}^{-}_{(aq)}$	Electrons transfer from the reactant to the product. (Students did not know that electrons could only transfer between reactant particles; the oxidizing agent and reducing agent always act as reactants).
B	Electrons transfer from $\text{Br}^{-}_{(aq)}$ to $\text{Cl}_{2(g)}$	This is the right answer. Students who wrote this is wrong may hold a misconception.
C	In this reaction, the oxidizing agent is $\text{Cl}^{-}_{(aq)}$ because it received electrons	Students did not understand that a chlorine ion $\text{Cl}^{-}_{(aq)}$ could not take electrons as the chlorine oxidation number in this particle is minimal. (Students thought that it was an oxidizing agent and could receive electrons because the obtained chlorine ion was negative).
D	$\text{Br}_{2(l)}$ is the reducing agent in the reaction since the oxidation number of the bromine atoms went up from -1 in $\text{Br}^{-}_{(aq)}$ to 0 in $\text{Br}_{2(l)}$	Confusion between the meaning of the concepts oxidizing agent and reducing agent in the competition for electrons.
E	$\text{Cl}^{-}_{(aq)}$ is a reduction product in this reaction	Confusion between the concepts of “reducing agent” and “has been reduced”, and “oxidizing agent” and “has been oxidized” (which in any case regard the reactants). Confusion between “has been reduced” (reactant) and “reduction product” (product), and between “has been oxidized” (reactant) and “oxidation product” (product).
F	Electrons transfer from $\text{Br}^{-}_{(aq)}$ to $\text{Br}_{2(l)}$	Electrons transfer between the reactant and the product. (Students did not know that electrons could only transfer between reactant particles (the oxidizing agent and reducing agent are always reactants)).

Evidence received from teachers and students

The teachers related their classroom observations: some students insisted on knowing what the purpose of the task was and if its results would impact their summative assessment. 75% of the students stated that the task was simple, clear, and very easy, although their answers reflected unconscious misconceptions. Students were content with the task and perceived it as a pleasing challenge.

As for the teachers, 89% confirmed that the students actually held the misconceptions included in the task (namely, that no further changes were required in the diagnostic task). 22% of teachers reported that they were not surprised to discover that the students held those misconceptions because they had frequently encountered them earlier in their classes. Yet, 56% of the teachers said they were appalled by their students' answers. Although the students found the task simple and clear, many of them, including high achievers, did not determine correctly which of the particles was the oxidizing agent and which the reducing agent. All the teachers regarded the task favourably, saw it as highly effective, and said they would strongly recommend their colleagues to run it in their classrooms. 50% of teachers suggested assigning the task online (e.g., using the Google Forms app.) to automatically map the students' misconceptions and later treat them accordingly. They also reported that the phrasing of the task was clear and the students did not request clarifications while working through it. The diagnostic task was consequently approved without further changes (Treagust, 1988).

Stage 5: Introducing the improved diagnostic task to experimental implementation teachers.

The experimental implementation teachers received the improved diagnostic task for trial. This time too, we received no comments that required making changes to the diagnostic task. After the teachers tested the task with their students, the development and diagnostics forum discussed the task features in further detail, and came up with new recommendations to make the CPKs friendlier to the teachers who use it. The recommendations included running the task online, adding to the CPK the estimated time required to complete the task (15–20 min), adding a verbal description of the diagnosed misconceptions, adding a scoring rubric to the task, and writing down the possible sources of students' misconceptions based on the team's experience and the literature (Kind, 2004; Zoller, 1990). Another recommendation was to add didactic instructions for the teachers, such as specifying that the task be assigned after the students have learned the topic rather than using it to determine previous knowledge and completing it in class rather than as homework or a home quiz. All the recommendations have been adopted.

Stage 6: Developing pedagogical treatments.

One member of the development team undertook to develop and prepare pedagogical treatments meant to illustrate and correct the misconceptions and difficulties detected in the diagnostic task by applying DI strategies.

Development considerations

Each pedagogical treatment and activity developed had a specific rationale and purpose. In this section we describe the treatments (students' sheets are presented in Appendices B–E) and the rationale behind each treatment.

The first treatment involves a jigsaw puzzle aimed to deal with students' confusion between the terms oxidizing agent, reducing agent, oxidation product, and reduction product. The students have to piece together four oxidation-reduction reactions, while paying attention to the different colours of reactants and products, electron transfer from one reactant to another, and inserting the concept tags (oxidizing agent, reducing agent, oxidation product, and reduction product) in their appropriate places in each reaction (See Appendix C).

The treatment has two goals: (1) Help the students differentiate between reactants and products in a chemical reaction, specifically oxidation-reduction, (2) make the students understand that the oxidizing

agent and the reducing agent are both reactants. Experience shows that when students are asked to determine the oxidizing particle and the reducing particle, they often select a particle from the products. When students physically tag the participating particles (oxidizing agent, reducing agent) they realize that their right place is on the left side of the reaction, the side of the reactants, and not on the right side of the products. This helps them figure out in their minds the correct model of the redox reaction. A treatment of this kind introduces a new gaming element into the learning process, while incorporating the necessary chemical aspects. By making the learning more Entertaining, it increases the students' motivation and engagement (Fiskaa, 2005; Van Tassel, 1994).

The second treatment involves drawing a Lewis electronic representation. It aims to address students' difficulty distinguishing between an oxidizing agent and a reducing agent in the competition for electrons, specifically in halogen ions. This basic treatment ensures that students understand that electrons transfer from particle A in one reactant to particle B in the second reactant. Namely, electron transfer occurs between the reactants. It is a hands-on treatment where the students have to stick small black circles that stand for the electrons on top of larger circles symbolizing the ions of the given reaction to create a Lewis model for both reactants and products. This makes the process of electron transfer more tangible, allowing electron transfers using stickers (McIntosh & Warren, 2013) (Appendix D).

The third treatment responds to students' trouble to differentiate between the concepts of oxidizing agent and reducing agent. They have difficulty understanding that the electrons coming out of a reducing agent particle are the same electrons that transfer to the oxidizing agent. All the class students play a catch ball game in the school yard, where the ball represents the electrons. The student who throws the ball plays one reactant, and the student who catches it plays the other reactant. The thrower announces which particle he represents (oxidized or reduced), and whether the oxidation number has increased or decreased. The ball game helps the students internalize the process, by combining body movement and gaming with conceptual understanding (Danipog & Ferido, 2011).

The fourth treatment, "Three in a row", is based on the tic-tac-toe game, and deals with students' difficulty in distinguishing between the concepts, oxidizing agent, reducing agent, oxidation product, and reduction product by looking closely at mixed oxidation-reduction and other reactions on a 3×3 reaction board. The students identify the role of the marked particle in each reaction, and search for a sequence of three reactions in a column, row, or diagonal, where the marked particle is an oxidizing or reducing agent, or an oxidizing or reduction product (Appendix B). Practice in identifying oxidation-reduction reactions and their components becomes less tedious and more effective since it is incorporated in a game.

The fifth treatment is, in fact, not a corrective treatment but an advanced activity for students who have answered correctly the entire diagnostic task. It introduces them to a more advanced stage in oxidation-reduction that is not included in the curriculum. The activity involves disinfecting a swimming pool by chlorine – $\text{Cl}_2(\text{g})$, a material the students probably come across in everyday life. Since these students are likely to complete the game in a short time, we recommend assigning them a complex activity or two activities in a row, to fit into the timeframe of the Rest of the class (see Appendix D).

Stage 7: First pilot of CPK activation.

Content validation by experts. The development team met for an initial trial run of the developed kit.

Trial considerations

The team members simulated students going through the different DI pedagogical activities (treatment 1–5). During the trial, each team member noted down comments and suggestions, which were later collected and discussed. Based on those comments, the development team made improvements to the kit's pedagogical activities, as shown in Table 2.

Table 2: Improvements made to the oxidation-reduction kit following initial trial run.

Misconception/difficulty: Comments made at stage 7 of the development	Original pedagogical treatment proposed for the misconception/difficulty	Improved pedagogical treatment of the misconception/difficulty
1. Confusion between an oxidizing agent and a reducing agent in the competition for electrons	<p>A. Catch game outside the class, to go over the terms oxidizing agent and reducing agent, has been oxidized, has been reduced, oxidation number.</p> <p>B. A practice sheet to recall the oxidation-reduction reaction in halogens, with guiding questions for discussion. The students mark the oxidizing agent, reducing agent and oxidation/reduction product.</p>	<p>A. The full class participates in a preliminary catch game, to refresh the meaning of the terms before engaging in pedagogical treatment activities.</p> <p>B. A section added to the sheet practices building a reaction model. Large colored sticky circles represent the particles, and small black circles represent electrons that can be fastened onto them (Appendix D).</p>
2. An electron transfers from the reactant to the product. Students do not realize that electron transfers occur exclusively between reactant particles (the oxidizing agent and the reducing agent are always reactants)	<p>C. A card puzzle. The four redox reactions appear in color. Marked on them are the oxidizing agent and reducing agent particles, oxidation products, reduction product, and an arrow that shows electron transfer. The students have to put together cards representing the four reactions.</p>	<p>C. An additional textless version of the cards was prepared. Students may choose to go directly to this version or start with the texted one if they have difficulty (Appendix C).</p>
3. Confusion between reducing agent/has been reduced; oxidizing agent/has been oxidized (all involving reactants).	<p>D. Game inspired by tic-tac-toe. Students receive three 3×3 boards representing reactions with colored particles. They have to find three rows of colored particles (horizontal, vertical, or diagonal) that are oxidizing agents, reducing agents and oxidation products. The game may be played individually or in a group, with a discussion.</p>	<p>D. A fourth board was added, where the students had to find a row of reduction products (Appendix B).</p>
4. Confusion between has been reduced (reactant) and reduction product (product); has been oxidized (reactant) and oxidation product (product).		

Stage 8: Experimental run of the complete CPK by chemistry teachers.

This stage comprised a first run of the full kit, i.e., the diagnostic task and all the treatments for the misconceptions. The experimental implementation teachers experienced the CPK as learners and provided feedback, according to which improvements were made to the kit, as shown in Table 3.

Stage 9: Implementation test-run of the CPK by experimental implementation teachers in their classes.

The experimental implementation teachers ran the kit in their classes under supervision of the research team. A member of the development team received the findings and comments, and made final adjustments to the kit. Very few significant comments were added at this stage. Most of the required improvements regarded the wording in the students' instruction pages. This was a stage of structure and content validation, and external validation. After this, the kit underwent final graphic design and became available to all chemistry teachers.

Understanding the CPK impact on students

During the development, activation and validation of the CPK, we kept asking the experimental teachers for feedbacks about it. They reported positive responses from the students due the treatments that helped them overcome the misconceptions discovered in the diagnostic task. The teachers' feedbacks revealed the following: Students had varied preferences for different treatments., 22% of the students who received a

Table 3: Improvement of redox kit following second run (stage 8).

Comments on misconceptions/difficulties received at development stage 8	Pedagogical treatment as proposed after stage 7	Pedagogical treatment following improvement in stage 8
Activity designed for students who carried out the diagnostic task correctly	Advanced oxidation-reduction exercise where students had to answer questions, explain their answers, and discuss them	Additional activity: these students had to choose and pursue one other activity their peers went through
Summary activity (“complete the circle”) (see Appendix E)	None	Summary activity for the whole class: The class is divided into three or four heterogeneous groups of students of all levels. Each group receives circle segments with questions and answers on oxidation-reduction, and has to match the questions with the correct answers to form a complete circle.

relevant treatment did not enjoy working in a group; 60% of the students, even ones who did not tend to participate in in class activities, thought the games were an interesting and engaging experience. Furthermore, teachers’ observations and impressions after running the treatment in the classroom indicated that the puzzle had very favourable repercussions among 55% of the students, and that teachers and students alike were enthusiastic about it.

Analysis of students’ answers to the diagnostic task indicated that the treatment decreased the number of misconceptions and difficulties about oxidation-reduction reactions following the treatments (see Figure 4). The students’ scores in the diagnostic task and the post-treatment evaluation task that required similar levels of understanding and skills also revealed a significant improvement.

Discussion

The discussion follows the study’s research questions (RQ).

(RQ1) What are the main aspects of the CPK development and validation processes?

There are several models for designing education interventions, differing in the purpose of the intervention, the points the researchers wish to highlight, and the research questions (Plomp & Nieveen, 2013). Yet, the

Figure 4: Distribution of misconceptions/difficulties in the oxidation-reduction diagnostic task before and after the implementation of the kit’s Redox treatments

principles and development stages of all the models are very much alike: conceptualization and definition, exploration, design, development and evaluation (Barab & Squire, 2004). Thus, for example, the model proposed by Nieveen, McKenney, & Van den Akker (2006) begins by developing a framework and primary plan of intervention. Next comes designing a prototype that undergoes evaluation by experts, followed by a series of improvements that finally yield an applicable version that meets the goals of the intervention. An experimental implementation indicates whether the target audience (the teachers) is able and willing to apply the intervention in class, and whether the intervention is effective. A similar model proposed by Mafumiko (2006) includes conceptualization, definition of problem and need, data gathering in the natural environment (the classrooms) and in relevant literature, designing a primary intervention version, expert evaluation, development of a second version, pilot implementation, third version, experimental implementation, final version and field test.

The development process of CPKs described in this paper largely resembles the models proposed in the literature, involving a detailed process of design – validation – evaluation carried out by a large group of professionals. Content experts, diagnostic consultants, students, in-service teachers, teacher educators, and science education researchers cooperated to achieve the desired pedagogical product. The process had three main goals: (1) Ensuring the validity of the intervention under development, (2) Ensuring that the process is consistent, (3) Observing ethical rules and preventing any conflict of interest that might arise from the researcher's association with the development and design team, as reported and recommended in the literature (McKenney, Nieveen, & van den Akker, 2006).

(RQ2) What effects did the pedagogical treatments suggested in the redox CPK have on students?

The kits broaden the teaching strategy by offering diverse pedagogical treatments that helped teachers define better the learning outcomes of their students and their areas of interest. The CPK made the students' misconceptions surface. The analysis revealed about 650 appearances of misconceptions in the diagnostic task among the students sampled. It also showed that the percentage of the misconceptions' appearances about redox reaction among students has decreased after the treatment with the CPK. Moreover, the percentage of correct answers after treatments increased, consistent with the literature on the effect of correcting misconceptions on students' comprehension processes (Heacox, 2002). All these changes confirmed our hypothesis. In conversations held with students following the treatments, they expressed their satisfaction with the treatments, and said they enjoyed them, found them interesting, actively participated in them. Some students also reported that they felt closer to their teachers because they appreciated their desire and efforts to diversify their teaching and look for creative solutions to improve their chemistry understanding. Others believed this helped improve class management and engaged most of the students. Consequently, chemistry learning in class has become more productive and significant.

(RQ3) What challenges, frequently mentioned in the literature as hindering DI, do the CPK developed in the present research address?

The relevant literature reports that the main challenges facing differentiated instruction are time constraints, workload, class management, and teachers' views about the role of the school management in creating a change (Corley, 2005). Also mentioned is the need to overcome administrative obstacles resulting from insufficient understanding of the process by the pedagogical leadership and school principals, which hinders the change from gathering momentum (Richardson, 2007). The response to intervention (RTI) model that stood at the basis of the CPKs described in the present research has also encountered several implementation challenges.

According to Compton, Fuchs, Fuchs, & Bryant (2006), the implementation of an RTI model had once over-emphasized the scanning and mapping of students, which was straightforward, given the easy access to school data. At the same time, there was an almost complete disregard for the follow-up and supervision of students' progress and performances. The teaching, which should have considered the needs, level, progress, and learning profile of the students, was not adjusted or diversified. To overcome this problem, the kit development described in this study devoted special attention, after the diagnostic stage, to customized pedagogical treatments, and to complete the ongoing learning evaluation by the evaluation task. This allows chemistry teachers to apply the CPK to all the stages of the RTI model – diagnosis, personalized instruction (PI) response, and re-diagnosis.

Among the most important contributions that the CPK makes to resolving chemistry teaching problems are the ready-made diagnostic tasks that expose student misconceptions standing in the way of effective learning. The kit includes instructions, tips, and didactical advices regarding class management during implementation, to overcome time management difficulties that arise in DI (Corley, 2005). It offers teachers ready-made pedagogical treatments with the required accessories as well as replies to the diagnostic and evaluation tasks. It addresses the misconceptions and difficulties encountered in chemistry learning, and reduces the teachers' workload by eliminating the need to buy materials necessary to devise pedagogical treatments on their own (Heacox, 2002).

The CPK developed in the present study has succeeded in resolving many of the difficulties and challenges mentioned in the literature as obstructing the implementation of DI:

1. Lack of psychological and pedagogical preparedness of the teachers. Some teachers believe that PI is unjust, treating students differently according to their needs.

The CPK development team has arranged for courses and continuing programs for chemistry teachers to further develop their skills in chemistry teaching in a heterogeneous class. These programs explain the DI rationale, introduce the kits, and enable experiencing their use in class. Moreover, incorporating the teachers' comments into the development process affects the final design and creates in the teachers a sense of ownership of the CPKs under development (Blonder, Kipnis, Mamlok-Naaman, & Hofstein, 2008). Combined, the above measures assist the teachers in overcoming negative views about PI, and dealing with any sense of injustice they may have had about treating individual students differently according to their needs.

2. The need to find ways to tone down the visibility of group differences, to blur the division into fast- and slow-learning groups.

During the implementation of the developed kits in class, the teachers have the option of allowing students to participate in additional activities over those assigned to their group. This blurs the division into groups and helps the students overcome their reservations about being divided into groups according to their level. During the pilot run, several students objected to the division into groups in advance. Nevertheless, the teachers succeeded in implementing the kits and motivating the students to take part in the activities by allowing them to participate in another pedagogical activity in addition to the one assigned to them.

3. One-time scanning of the students and their achievements resulted in an inaccurate classification of students by the school.

The kits comprise an evaluation task identical to the diagnostic one, allowing teachers to monitor the students' progress and the effect of the CPK on their performances.

4. The currently used uniform intensive small-group support program mainly depends on the allocation of additional teaching hours. While some of the students benefit from this intensive program and make progress, the program overlooks students who need a long-term personalized program.

Limitations

While we have found solutions for the challenges in DI implementation, additional challenges emerge, which we have not addressed as they regard the administrative system of the school. They include the stands of

teachers towards the school management and its role in bringing about change (Corley, 2005), devising ways to allocate the required budgetary resources (Heacox, 2002), tackling administrative obstacles resulting from the school principals' and other educational leaders' insufficient understanding of the process required to promote change (Richardson, 2007; Tomlinson, 2003).

The CPK development process described in this article has several limitations already mentioned in the literature (Barab & Squire, 2004; Mafumiko, 2006; Nieveen, McKenney, & Van den Akker, 2006), involving the different stages of research validation. In a research-based development process, the intervention under development undergoes recurrent revision based on findings emerging from field tests. In the present research, two stages of revision preceded the final product. The first was a pilot run carried out with teachers, and the second was a field experiment carried out with students. Due to the dictations of the Israeli chemistry curriculum sequence, the teachers were often unable to implement the kits in their classes immediately after experiencing the pilot run for reasons beyond their control. There was, therefore, a gap between the first validation stage and the second stage of improvement. Obviously, additional changes might further improve the kits, but such improvement would come at the price of a significant delay in implementing the kits in Israeli chemistry classes.

Conclusions and summary

Previous studies (Barab & Squire, 2004; Mafumiko, 2006; Nieveen, McKenney, & Van den Akker, 2006) have proposed three generic criteria to ensure the quality of the design and development of interventions: validity (relevance), practicality, and effectiveness. An intervention must respond to an existing need, its components should be based on up-to-date knowledge to ensure their validity, and they should be coherent and consistent. The target users, teachers in the current study, must perceive the intervention as practical and applicable as intended by the developers, and yielding the aspired results. During the experimental implementation, we noticed that previous practical intervention experience of those applying the kits is advantageous, as it offers the educational research team feedbacks regarding the practicality of the prototypes and enhances further evaluation.

Keeping aware of the difficulties and challenges facing the design and development of pedagogical intervention programs is crucial to the process. In the development process described in this article, we set targets intended to resolve some of those difficulties and challenges. The development team continues developing additional chemistry CPKs along the lines described in this article.

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Appendix A: The redox diagnostic task (student sheet)

Oxidation and reduction, which is the reducing agent?

Here is the reaction:

- (1) For each statement, determine whether it is correct for the above reaction.
- (2) Correct the wrong answers.

Section	Statement	Right or Wrong?	Corrected statement
a.	Electrons transfer from $\text{Br}^-_{(\text{aq})}$ to $\text{Cl}^-_{(\text{aq})}$		
b.	Electrons transfer from $\text{Br}^-_{(\text{aq})}$ to $\text{Cl}_{2(\text{g})}$		
c.	In this reaction, the oxidizing agent is $\text{Cl}^-_{(\text{aq})}$ because it received electrons		
d.	$\text{Br}_{2(\text{l})}$ is the reducing agent in the reaction since the oxidation number of the bromine atoms went up from -1 in $\text{Br}^-_{(\text{aq})}$ to 0 in $\text{Br}_{2(\text{l})}$		
e.	$\text{Cl}^-_{(\text{aq})}$ is a reduction product in this reaction		
f.	Electrons transfer from $\text{Br}^-_{(\text{aq})}$ to $\text{Br}_{2(\text{l})}$		

(3) Choose one of the wrong statements and explain why it is wrong.

(4) Mark by $\checkmark$ the extent to which you found the task difficult.

1	2	3	4	5
Very easy				Very difficult

Have fun!

Appendix B: Personal game (tic-tac-toe)

(1) Three-in-one reducing agents

The board displays three reactions. In each reaction, the substance is marked in red. Select the reactions where the substance in red is a **reducing agent**.

$\text{Fe}_{(\text{s})} + 2\text{Fe}^{3+}_{(\text{aq})} \rightarrow 3\text{Fe}^{2+}_{(\text{aq})}$	$\text{Br}_{2(\text{l})} + 2\text{I}^-_{(\text{aq})} \rightarrow 2\text{Br}^-_{(\text{aq})} + \text{I}_{2(\text{s})}$	$\text{CO}_{2(\text{g})} + \text{Mg}_{(\text{s})} \rightarrow \text{CO}_{(\text{g})} + \text{MgO}_{(\text{s})}$
$\text{PbSO}_{4(\text{s})} + \text{H}_2\text{S}_{(\text{g})} \rightarrow \text{PbS}_{(\text{s})} + \text{H}_2\text{SO}_{4(\text{l})}$	$\text{Cu}_{(\text{s})} + \text{H}_2\text{O}_{(\text{l})} + \text{N}_{2(\text{g})} \rightarrow \text{CuO}_{(\text{s})} + \text{NH}_{3(\text{g})}$	$\text{CaO}_{(\text{s})} + \text{CO}_{2(\text{g})} \rightarrow \text{CaCO}_{3(\text{s})}$
$\text{ClO}^-_{(\text{aq})} + \text{HNO}_{2(\text{aq})} \rightarrow \text{HNO}_{3(\text{aq})} + \text{Cl}^-_{(\text{aq})}$	$\text{Zn}_{(\text{s})} + 2\text{H}_3\text{O}^+_{(\text{aq})} \rightarrow \text{Zn}^{2+}_{(\text{aq})} + \text{H}_{2(\text{g})} + 2\text{H}_2\text{O}$	$2\text{Na}_{(\text{s})} + \text{Cl}_{2(\text{g})} \rightarrow 2\text{NaCl}_{(\text{s})}$

The game ends when you obtain a column, a row or a diagonal line where the substance in red in all the three reactions is a **reducing agent**.

(2) Three-in-one oxidizing agents

The board displays three reactions. In each reaction, the substance is marked in green.

Select the reactions where the substance in green is an **oxidizing agent**.

$\text{Fe}_{(\text{s})} + 2\text{Fe}^{3+}_{(\text{aq})} \rightarrow 3\text{Fe}^{2+}_{(\text{aq})}$	$\text{Br}_{2(\text{l})} + 2\text{I}^-_{(\text{aq})} \rightarrow 2\text{Br}^-_{(\text{aq})} + \text{I}_{2(\text{s})}$	$\text{CO}_{2(\text{g})} + \text{Mg}_{(\text{s})} \rightarrow \text{CO}_{(\text{g})} + \text{MgO}_{(\text{s})}$
$\text{PbSO}_{4(\text{s})} + \text{H}_2\text{S}_{(\text{g})} \rightarrow \text{PbS}_{(\text{s})} + \text{H}_2\text{SO}_{4(\text{l})}$	$\text{Cu}_{(\text{s})} + \text{H}_2\text{O}_{(\text{l})} + \text{N}_{2(\text{g})} \rightarrow \text{CuO}_{(\text{s})} + \text{NH}_{3(\text{g})}$	$\text{CaO}_{(\text{s})} + \text{CO}_{2(\text{g})} \rightarrow \text{CaCO}_{3(\text{s})}$
$\text{ClO}^-_{(\text{aq})} + \text{HNO}_{2(\text{aq})} \rightarrow \text{HNO}_{3(\text{aq})} + \text{Cl}^-_{(\text{aq})}$	$\text{Zn}_{(\text{s})} + 2\text{H}_3\text{O}^+_{(\text{aq})} \rightarrow \text{Zn}^{2+}_{(\text{aq})} + \text{H}_{2(\text{g})} + 2\text{H}_2\text{O}$	$2\text{Na}_{(\text{s})} + \text{Cl}_{2(\text{g})} \rightarrow 2\text{NaCl}_{(\text{s})}$

The game ends when you obtain a column, a row or a diagonal line where the substance in green in all the three reactions is an **oxidizing agent**.

(3) Three-in-one oxidation products

The board shows reactions. In each reaction, the substance is marked in yellow.

Select the reactions where the substance in yellow is an **oxidation product**.

$\text{Fe}_{(\text{s})} + 2\text{Fe}^{3+}_{(\text{aq})} \rightarrow 3\text{Fe}^{2+}_{(\text{aq})}$	$\text{Br}_{2(\text{l})} + 2\text{I}^-_{(\text{aq})} \rightarrow 2\text{Br}^-_{(\text{aq})} + \text{I}_{2(\text{s})}$	$\text{CO}_{2(\text{g})} + \text{Mg}_{(\text{s})} \rightarrow \text{CO}_{(\text{g})} + \text{MgO}_{(\text{s})}$
$\text{PbSO}_{4(\text{s})} + \text{H}_2\text{S}_{(\text{g})} \rightarrow \text{PbS}_{(\text{s})} + \text{H}_2\text{SO}_{4(\text{l})}$	$\text{Cu}_{(\text{s})} + \text{H}_2\text{O}_{(\text{l})} + \text{N}_{2(\text{g})} \rightarrow \text{CuO}_{(\text{s})} + \text{NH}_{3(\text{g})}$	$\text{CaO}_{(\text{s})} + \text{CO}_{2(\text{g})} \rightarrow \text{CaCO}_{3(\text{s})}$
$\text{ClO}^-_{(\text{aq})} + \text{HNO}_{2(\text{aq})} \rightarrow \text{HNO}_{3(\text{aq})} + \text{Cl}^-_{(\text{aq})}$	$\text{Zn}_{(\text{s})} + 2\text{H}_3\text{O}^+_{(\text{aq})} \rightarrow \text{Zn}^{2+}_{(\text{aq})} + \text{H}_{2(\text{g})} + 2\text{H}_2\text{O}$	$2\text{Na}_{(\text{s})} + \text{Cl}_{2(\text{g})} \rightarrow 2\text{NaCl}_{(\text{s})}$

The game ends when you obtain a column, a row or a diagonal line where the substance in red in
All the three reactions are **oxidation products**

Appendix C: Building redox reactions. A treatment in the redox CPK

- (1) Build 4 different redox reactions (pay attention to the color of the reducing agent and the oxidizing agent)
- (2) Find 2 similarities within the 4 reactions
- (3) Find 2 differences between the 4 reactions
- (4) Suggest general ideas to redox reactions

Choose: The reducing agent and the oxidizing agent are in: the reactants/the products/it depends on the reaction

Continued.

Appendix D: The activity designed for students who have difficulty distinguishing between oxidizing agent and reducing agent in the competition for electrons, specifically in halogen ions diagnostic task

Following is a redox reaction between a halogen and a halogen ion.

- (1) To understand the reaction you must identify the oxidizing agent (which is, of course, in the reactant). Halogens are oxidizing agents. They strongly attract electrons.
- (2) Which of the halogen family members attracts electrons more strongly? How have you reached this conclusion? Could the concept “electronegativity” help you in this context?

Following is an electron representation formula (after Lewis) of the particles participating in the reaction:

- (3) Add an arrow to describe electron transfer between the reducing agent and the oxidizing agent in the reactant. Explain the arrow’s direction using the following terms: electronegativity, strong oxidizing agent.
- (4) Below are model construction tools comprising four large black circles labeled Br and Cl, and 14 small adhesive black circles.

Based on the reaction described in para. 2, construct the electron representation (Lewis structure) of all the reaction components using the provided tools.

Appendix E: An activity designed for students who understand the process of electron transfer between the reactants in a redox reaction and solve correctly the diagnostic task

Activity 1

Below is a reduction–oxidation reaction that occurs when chlorine $\text{Cl}_2(\text{g})$ is used to purify a swimming pool:

1. $\text{Cl}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{ClOH}(\text{aq}) + \text{HCl}(\text{aq})$
 - A. List the oxidation numbers.
 - B. Specify the oxidizing agent and reducing agent
 - C. What is special about this reaction?

A reaction in which the oxidizing agent and the reducing agent is the same substance is called a disproportionation reaction.

- D. What is the product of oxidation and what is the product of reduction?

Below are additional reactions of disproportionation. In each reaction, identify the oxidizing agent, the reducing agent, the oxidation product, and the reduction product.

2. $2\text{KClO}_3(\text{s}) \rightarrow 2\text{KCl}(\text{s}) + 3\text{O}_2(\text{g})$
3. $2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
 - E. Choose one reaction and present to the class the self-redox reactions.
 - F. Does the following reaction belong to the reactions where self-redox occurs? If so, explain. If not, what is special about it?
4. $2\text{H}_2\text{S}(\text{g}) + \text{SO}_2(\text{g}) \rightarrow 3\text{S}(\text{s}) + 2\text{H}_2\text{O}(\text{l})$

Activity (2) the oxidation-reduction cycle game, a summative collaborative activity.

Students have to reassemble the cutoff circle segments (containing questions related to oxidation-reduction, and their answers) and form a complete circle by matching the correct answers to the questions.

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