

Reflecting Socio-Scientific Issues for Science Education Coming from the Case of Curriculum Development on Doping in Chemistry Education

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Socio-scientific issue-based science education has been suggested for promoting general educational skills development in science classes. However, there is a lack of operationalized criteria, which can be used to reflect upon societal issues to whether turning them into issues for science classroom instruction. This paper describes a case study based on Participatory Action Research in science education. A lesson plan based on the socio-scientific issue of doping in professional sports and in fitness studios was designed and cyclically refined by a group of teachers and science education researchers. Along this case, together with previous studies of SSI-oriented curriculum development, the action research group started reflecting on the question of operational criteria for reflecting and carrying out socio-scientific issues in science classroom situations. This paper discusses the structure of the above-mentioned lesson plan. Experience gained during lesson plan development and testing will be reported upon. Suggestions stemming from teacher group discussions about the criteria chosen for reflecting socio-scientific issues for classroom use will also be presented.

Keywords: socio-scientific issues-based science education, curriculum development, participatory action research, doping, analytical chemistry education

INTRODUCTION

Quite regularly, science education in general and secondary chemistry education in particular have been listed among the most unpopular subjects among most students (Holbrook, 2008; Osborne & Dillon, 2008). A frequent explanation of this situation is that most science learners do not (or cannot) perceive the relevance of science and science education, especially in chemistry and physics. This results in low levels of student motivation (Jenkins, 2005; Osborne, 2003). One suggestion for improving students' perception of the

relevance of science has been to strengthen the societal dimension of science education (Hofstein & Kempa, 1985; Holbrook & Rannikmae, 2007; Solomon & Aikenhead, 1994; Yager & Lutz, 1995). This dimension is quite often a very much neglected area in science education (Hofstein, Eilks & Bybee, 2011; Hughes, 2000). Some research has suggested that increasing the societal orientation of science education will better prepare students for life in future (Elmose & Roth, 2005; Ware, 2001; Sjöström, 2013) and raise their personal perceptions of the relevance of science education (Fensham 2004a; Holbrook, 2003; Lee & Erdogan, 2007).

Many people have promoted the use of socio-scientific issues (SSIs) as a possible driving force for skills-oriented science education (Sadler, 2004; 2011; Zeidler Sadler, Simmons, & Howes, 2005). SSIs should not only serve as motivating contexts for science

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State of the literature

- A need for stronger inclusion of the societal dimension of science exists in most science classrooms.
- Socio-scientific issues have already proven themselves to be motivating and beneficial in the context of science education in previous studies.
- Socio-scientific issues in science education have the potential to promote both science learning and general educational skills.

Contribution of this paper to the literature

- This paper discusses how the issue of doping in sports can be used as a socio-scientific issue in science education.
- The current paper documents in-service experience, which shows that doping can be a motivating topic when used as a socio-scientific issue in science education.
- The results suggest several potential criteria that can aid educators in reflecting upon societal contexts in order to use them as socio-scientific issues in science education.

learning, but also provide a catalyst to spark general educational skills (Sjöström, 2013), like argumentation (Albe, 2008) and decision-making abilities (Simon & Amos, 2011).

Within the SSI-based science education movement, some ten years ago the socio-critical and problem-oriented approach to science education was developed in Germany. This approach originally saw the light of day in the 1990s with the introduction of a lesson plan centering around the use of biodiesel (Eilks, 2002a). Many later examples have been developed using the model of Participatory Action Research as a collaborative strategy for curriculum development and classroom-based research in science education (Eilks & Ralle, 2002). Teaching units have been published e.g. on low-fat, low-carb diets (Marks, Bertram & Eilks, 2008), musk fragrances in shower gels (Marks & Eilks, 2010) or the use of bioethanol as an alternative fuel source (Feierabend & Eilks, 2011). Different research-based suggestions for the science classroom were derived from these units. The resulting ideas include e.g. a five-step model to structure SSI-based classroom activity (Marks & Eilks, 2009) or new pedagogies, which mimic the processes how science-related information is both transferred and employed in societal debate (Eilks, Nielsen & Hofstein, in print).

This paper examines another example of the socio-critical and problem-oriented approach to science teaching developed by Participatory Action Research

(Eilks & Ralle, 2002). The SSI of sports doping was selected as the context for promoting subject-matter learning as well as general educational skills, since it involves not only a background in science, but also societal decision-making processes regarding doping questions. During the cyclical refinement process, the Participatory Action Research group started focusing on refining criteria as originally suggested by Marks and Eilks (2009) necessary to effectively reflect upon questions taken from society for use as SSIs in the science classroom. This paper discusses both the lesson plan and the action research group's path towards a better understanding the reflection and selection of socio-scientific issues for classroom use.

METHOD

The current lesson plan was developed according to the model of Participatory Action Research (PAR) in science education (Eilks & Ralle, 2002) as it has also been suggested by Pedretti and Hodson (1995) to use Action Research to implement societally driven education in science classrooms. For more than a decade, many studies have been carried out that show PAR's potential for evidence-based curriculum design and for promoting continuous professional development of teachers (Marks & Eilks, 2010; Mamlok-Naaman & Eilks, 2012).

PAR is a collaborative process, which combines curriculum change with classroom-based research. University researchers and in-service teachers cooperate to merge evidence-based knowledge stemming from educational research with practical experience taken from classroom settings. Both sources constitute a knowledge spectrum, which is important for innovation in teaching and learning. Each area has its own strengths and weaknesses (McIntyre, 2005). The development and classroom-based research phases during PAR are part of a cyclical process (Figure 1). Lesson plans are collaboratively drafted, tested, evaluated, and then revised. Main focal points of the entire process include the improvement of authentic teaching practices and the continuous professional development of the practitioners. The process also aims at collecting empirical evidence which shows the effects of changed practices in the classroom and aids in the dissemination of innovative classroom practices (Marks & Eilks, 2010).

The lesson plan on doping was developed by a group of ten teachers from different schools in Germany, who worked together for over a decade prior to creating this teaching unit (Mamlok-Naaman & Eilks, 2012). This PAR group has also developed many similar lesson plans and carried them out in classroom situations (e.g. Marks & Eilks, 2010). The teachers and researchers meet regularly once a month for a whole afternoon. For

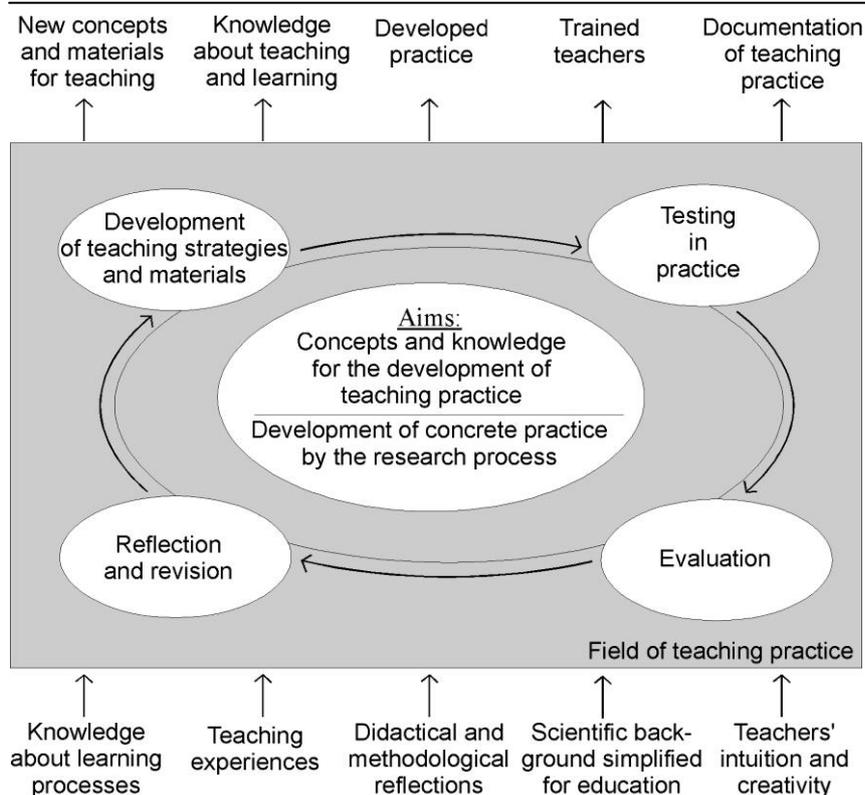


Figure 1. Participatory Action Research in science education (Eilks and Ralle, 2002)

this particular topic, the team needed about a year to finish the lesson plan.

By the end of the development phase, the lesson plan was tested in one tenth-grade and three eleventh-grade classes in German high schools. A total of 80 students (age range 15-17) took part in the case study. The data collected included teacher feedback during the group discussions in the monthly meetings of the action research group. Teacher reflection in this case was focused on finding potential criteria for effectively reflecting upon SSI-based topics in science education. A student questionnaire composed of open and Likert questions was also employed to record student feedback. Participants were asked about the feasibility of the lesson plan and their opinion of both the topic and how it was taught. The data sources were then qualitatively analyzed and triangulated to construct meaning.

The lesson plan

Socio-critical and problem-oriented science teaching

The socio-critical and problem-oriented approach to science education focuses on increasing learners' motivation and the perception of relevance in science teaching, just as similar approaches do (Osborne, 2003). This method attempts to explicitly prepare students to both understand and take part in societal consensus-

building and decision-making processes dealing with technical and scientific questions. This approach is quite typical for socio-scientific issues-based curricula (Sadler, 2011).

The theoretical basis of socio-critical and problem-oriented science teaching points researchers towards a consistent model for structuring SSI-based teaching. After comparing teachers' development of SSI-based lesson plans in many case studies, Marks and Eilks suggested a model for structuring lesson plans in 2009. They outlined a set of goals within the model. These included: 1) an orientation centering on the unique German concept of "Allgemeinbildung" (general education) which has recently found its way into the international literature (Fensham, 2004b; Elmose & Roth, 2005; Hofstein et al, 2011, Sjöström, 2013), 2) a stronger link to the idea of 'education through science' rather than 'science through education' (Holbrook & Rannikmae, 2007), 3) a promotion of multidimensional scientific literacy (Bybee, 1997) and 4) skills development in the areas of communication and evaluation, particularly societally oriented argumentation and decision-making abilities. However, criteria for topic selection, some essential methodological components, and a tested pattern of the general steps in which the units tended to run were also addressed (Figure 2).

The socio-critical and problem-oriented approach introduces current, authentic science topics to the learners with the aid of everyday media. This includes

Objectives	Criteria for selecting issues and approaches	Methods	Structure of the lesson plans
Allgemeinbildung/ education through science	Authenticity	Authentic media	1. Textual approach and problem analysis
(Multidimensional) Scientific Literacy	Relevance	Student oriented chemistry learning and laboratory work	2. Clarifying the science background in a laboratory environment
Promotion of evaluation skills	Evaluation undetermined in a socio-scientific respect	Learner centred instruction and cooperative learning	3. Resuming the socio- scientific dimension
Promotion of communication skills	Allows for open discussion	Methods structuring controversial debating	4. Discussing and evaluating different points of view
Learning science	Deals with questions from science and technology	Methods provoking the explication of individual opinions	5. Meta-reflection

Figure 2. Framework of socio-critical, problem-oriented science teaching (Marks & Eilks, 2009)

the use of magazine articles, newspaper clippings, radio and television broadcasts, and brochures published by special interest groups, businesses, industry, and both consumer protection and environmental agencies. The media samplings showcase the various opinions of experts and special interest groups with their unique points-of-view. Questions are then derived from the pupils close contention with the media materials. All questions which specifically require scientific or technological knowledge to understand are clarified during a phase of subject-matter learning and practical work. After this, reevaluating exactly which questions have been answered (or not) returns the learners to the socio-scientific dimension of the issue. Reflection on how society handles and evaluates SSIs is provoked by exercises which mimic authentic social practices. Various possibilities exist for contrasting societal perspectives on the topic with societal decision making processes. These include conventional exercises like role-playing and business games, but other methods can also be employed. New pedagogies originally created for socio-critical and problem-oriented science teaching include the journalist method (Marks, Otten & Eilks, 2010) and working as a professional product tester (Burmeister & Eilks, 2012). Each of these methods highlights a societal practice which communities use to discuss and evaluate socio-scientific questions. These practices are reflected upon in the final phase of the lesson plan with a special focus on how society deals with questions about science and technology (Eilks et al., in print). In end effect, such teaching units provide learners with access to controversial aspects of a problem, give them a techno-scientific clarification of

important questions, then require them to take a closer look at the problem, armed with more and better information than they had at the initial contact. The final exercise contrasts the various opinions and points-of-view expressed in the materials and by the learners themselves. It concludes with a closing round of joint reflection on the discussion and decision-making process among the learners and within society.

The lesson plan

Access to the controversy

The lesson plan opens with a very popular German advertisement for caffeine shampoo, which explicitly describes the product in question as "Doping for your hair." This advertisement has already led to open controversy in society at large. The World Anti-Doping Agency (WADA) in particular has criticized the advertiser for using the word "doping" as if it were a positive or even praiseworthy act. At this point, the teaching unit then expands upon issue by presenting various media reports on sports doping cases found in TV reports and magazine articles. The topic's high media presence helps to reinforce its societal relevance. A question about authority is also raised at this juncture. Thanks to their media presence, most students will know some relevant persons in positions of authority such as politicians. For example, many can name the government minister responsible for sports, including well-known doping experts. Pupils also know about other so-called "authorities" participating in the doping debate like professional athletes, coaches, etc. In

Table 1. Possible topics and activities for learning at stations in the phase clearing up technical questions

Topic	Activity
gas chromatography	explanation of gas chromatography, if necessary aided by a model of the functions of chromatography
mass spectrometry	explanation of mass spectrometry and a thought experiment
spectroscopic methods	explanation of infrared and nuclear magnetic resonance spectroscopy and a matching game with fictitious IR spectrograms
screening tests	model attempt for sample and treatment screening based on chemical indicator reactions
thin layer chromatography	separation of ink using thin layer chromatography in an experiment
paper chromatography	separation of felt-tip pen colors using paper chromatography in an experiment
quick tests	detection of glucose with quick strips

Table 2. Combining subject matter learning with reflecting the limits of doping in a jigsaw classroom

Jigsaw classroom
Group A: Everyday doping – caffeine
Group B: Everyday doping – creatine
Group C: Sanctioned sport doping – EPO
Group D: Sanctioned sport doping – anabolic steroids
Group E: Unconscious doping – ephedrine in cold medicines
Group F: Unconscious doping – nandrolone in food additives

Germany, former national handball player Stefan Kretschmar has repeatedly stated his opinion on doping, often presenting unconventional views of the subject.

Beginning the lesson plan in this fashion leads to a discussion of when doping really begins. It also raises issues such as who can (should be allowed to) define substances as doping agents and who should set the final doping limits. It quickly becomes evident that a cops-and-robbers chase is taking place, in which "doping inventors" are trying to outwit and avoid "doping detectives." All of the above aspects deal directly with chemistry, biochemistry and analytical chemistry, although the latter field is mainly important for setting doping limits. Only detectable doping substances and testable levels thereof can be meaningfully sanctioned by the authorities.

Clarifying the scientific background by practical work

In the next phase, the learning-at-stations method (Eilks, 2002b) is used to examine various analytical strategies and procedures. This allows the learners to understand exactly what analytical chemistry does in general and specifically in the case of doping. The treatment is variable and flexible with respect to subject-matter difficulty and the grade level of the learning group. Our example was designed for grade 10 or 11 (age range 15-17) German chemistry classes. An overview is shown by Table 1. Various approaches (experiments, models and problems), analytical

techniques (chromatography and spectroscopy) and strategies (flash tests or screening tests) are covered.

The learning-at-stations phase is combined with a jigsaw puzzle classroom (Eilks, 2005) covering the various types of doping. The different varieties of doping (performance enhancement through everyday components of food, unintentional doping from forbidden substances in medication or food supplements, illegal doping in competitive sports) are connected to well-known substances selected from the doping debate (Table 2).

Resuming the societal debate

After the subject matter learning phase, a reflection occurs on which of the initial issues and questions could be answered with the help of chemistry background knowledge. Questions dealing with what exactly doping is, which substances might be employed, and how analytical chemistry approaches doping measurement become quite clear. What cannot be answered by science are questions about which practices actually constitute doping, whether dopers deserve punishment or not, and how society should handle doping in leisure sport and the fitness arena. Decisions in these areas need to be open to societal debate and spearheaded by societal bodies such as sports associations, the Olympic Committee or the World-Anti-Doping-Agency (WADA).

Elaboration and discussion of various perspectives

After reintroducing the socio-scientific dimension of the issue into the lesson, society's reaction to the topic is reflected upon. The lesson explicitly asks how and to what extent information borrowed from science and chemistry are included in societal debates – either explicitly or indirectly. This step can include further analysis of articles from newspapers and magazines. It is also possible to have the pupils create their own articles through the journalist method (Marks, Otten & Eilks, 2010). Another societal practice which is very prominent in the doping debate is the public discussion occurring in TV talk shows (Marks, Bertram & Eilks, 2008). The current test case employs a role-playing exercise in the form of a TV talk show in order involve the participants in the societal controversy. Various roles are assigned, including doping experts, hobby and professional athletes, journalists, and sports viewers. Role cards are distributed, which describe the basic viewpoints of the characters to be played. These cards include references to Internet pages, which providing the students with supporting material and basic ideas for their roles.

Meta-reflection

In order to introduce a meta-reflection phase, the floor is opened up to general discussion once the role-playing exercise is over. The pupils are given a forum to express and discuss their own opinions, questions and positions. As they reflect upon the role-playing phase, it is important for pupils to drop their role-playing personas and talk about why certain classmates did or did not play their roles well. It is also important to discuss why this particular list of character roles was selected for the exercise. It should become also clear that science and technology provide only a minor part of relevant arguments. Other important point may stem from economics or ethics. It will also become clear that many scientific arguments are used intentionally and others left out on purpose. The aim of every participant is to influence public opinion in accordance to her or his interest. This is also how science is used for societal decision making in the real world.

Experiences and selected results from the evaluation

As has previously been the case with studies using this curriculum model (e.g. Marks, et al., 2008; Marks & Eilks, 2010; Feierabend & Eilks, 2011; Burmeister & Eilks, 2012), this lesson was described in very positive terms by teachers due to its authentic and interdisciplinary character. The hoped-for, controversial

discussions were present from the beginning of the unit. The participants described them as one of the primary aspects of the teaching unit, which caused higher levels of pupil activity and led to more positive learner feedback on the lessons than normally is the case.

The pupils agreed strongly on the four-step Likert questionnaire (4 = "I agree" to 1 = "I do not agree"; average value: 2.5) that they had enjoyed the lesson plan, because they had dealt with more than just "chemical content" (average answer: 3.62). They also agreed (2.95) that they liked working on subject-matter which was authentic and interested them personally. In the open answer section, statements generally expressed an opinion that the topic had been personally interesting and relevant to the learners. Many students made connections between the topic and their everyday lives, e.g. concerning unconscious doping through dietary supplements and medication. They also supported the multi-dimensional view on the topic covering chemical, individual, and societal aspects. Some students stated that their initial rejection of doping in sports was supported. However, after the lesson they felt more competent in justifying their respective claims. In a question after the lesson plan was over, most of the students explicitly suggested initiating more rules, stricter controls, and better public information concerning doping both in professional sports and the fitness and leisure sports sector. Many students referred to potential health problems among dopers, but also explicitly referred to doping as a societal issue rather than an individual problem. Nevertheless, in personal statements many students discussed the potential consequences of doping practices for their own life and health, if they were ever to be exposed to it. They also remained firm in their rejection of doping in all areas of sports.

The students also responded positively with regard to the chosen pedagogy. The cooperative, inquiry-based pedagogy was positively viewed, because the learners could work together with their classmates to find joint solutions to challenging tasks (3.42). Science class was perceived as more enjoyable and less boring due to the fact that new working methods had been employed (3.55). This was especially visible in the role-playing exercise, which was considered to be an extremely positive addition to the normal pedagogies found in typical science education. Many responses in the open questions supported these findings and tendencies.

Overall, both the teachers and the students judged the lesson plan to be an enrichment to science teaching. The pupils liked the alternative curriculum approach a lot. The teachers described the lessons as very learner-oriented and learner-activating. They stated that their students were given access to analytical chemistry, a topic which their previous experience in school had

shown to be difficult and unmotivating in similar teaching situations.

A reflection on criteria for selecting socio-scientific issues for science classes

The question of how to select and structure contexts for context-based science education is still an issue of debate (De Jong, 2006; Gilbert, 2006; Hofstein et al. 2011). The same is true for the question of which socio-scientific issues (SSI) show the most promise for promoting science learning and general educational skills and how they should be taught (Sadler, 2011). Because of this, the special focus in the collaborative work of the current PAR-based curriculum unit was the refinement and operationalization of specific, effective criteria for reflecting upon topics chosen for SSI-based science education.

Originally the socio-critical and problem-oriented teaching model for science education suggested five aspects for topic selection (Figure 2): 1) authenticity, 2) relevance, 3) open-endedness with respect to societal questioning, 4) being openly discussable in a public forum, and 5) having a clear-cut relationship to science and technology. These criteria were thought to guide the teacher in reflecting on potential topics as SSIs for science education (Marks & Eilks, 2009). Although the group members worked within this curriculum framework for many years, they thought it would be valuable to expand the initial outline of the criteria with a clear and testable description.

The criteria found in Marks and Eilks (2009) were refined using selected aspects from teacher group discussions to justify the selection of doping as a topic. This not only occurred in the foreground of the newly-suggested lesson plan, but also with reference to earlier teaching experiences in previous case studies (e.g. Marks, Bertram & Eilks, 2008; Marks & Eilks, 2010). A few thoughts will serve to preface the situation, before the specified test criteria are outlined below.

Doping is an *authentic* societal issue, since it is very much alive in mass media and public discussions. Doping is authentic in its connection to worldwide, broadcasted sport events, like the Olympic Games or the "Tour de France" cycling competition. Even in periods between large, prestigious sporting events, however, doping is never forgotten. Debates continue about whether to ban or allow doping, including the question of how to deal with athletes who are suspected of using illegal substances or are positively tested for doping. A good example of this is the recent and prominent case of the US cyclist Lance Armstrong. For teachers and curriculum developers, this means that the authenticity of a topic for society and the life worlds of students can be tested and evaluated by asking the

question how widely available a topic in the media is that mirror society's mindset.

Doping is also a *relevant* issue, which is important for professional sports, sports politics, and mass media reporting on sporting events. However, it is also relevant for the normal citizen who watches sports media reporting. People may be positively or negatively motivated to continue watching sports due to doping scandals. But doping has an even more direct relevance in the lives of our pupils, which quickly becomes evident as soon as we leave the quite closely monitored arena of professional sports. What about doping in peripheral kinds of sports which receive little media coverage? What about substance abuse in the minor leagues or in the community sports associations in which our students probably play in the afternoon? Are the same rules valid for these areas and levels of skill? Are the rules actually enforced? What about nonprofessional sports, the personal fitness sector, and school sport? Is it even possible to forbid or monitor doping (even with illegal substances) in the personal fitness arena? Should adults outside of organized sports be allowed to dope as they see fit? The discussion can easily be intensified by asking if pupils with certain prescription medications should be removed from graded testing and evaluation situations in school. This lends itself to establishing testable criteria, because the question of relevance can be reflected upon by analyzing suggestions for public decision-making, e.g. legal restrictions. Scenarios can be selected where the final decisions will or will not have direct or indirect consequences on learners' lives, e.g. restricting aspects of one's personal life, freetime activities, or consumer behavior.

Doping is also an *open-ended question* in both the life worlds of our students and in professional sports. The question of exactly which substances should be declared as illegal doping agents is part of an open societal debate. Ultimately, it is the decision of sport-political committees. For example, caffeine was previously forbidden in various sport disciplines several years ago, whereas today this is no longer the case. Different points-of-view for all possible decisions exist in the societal debate. Contradicting opinions in the public debate can be found at every level of professional sports, for personal fitness and in the leisure sector. Some people urge more restrictive regulations and controls. Others plead for wider freedom in the use of chemical substances that enhance sport-relevant skills. As a criterion for deciding whether an issue is really open-ended, a simple analysis of the mass media will reveal whether various points-of-view are expressed and supported by substantial interest groups in a given society.

In order to make a SSI challenging, it is necessary to allow varying claims and contrasting ideas to be

Table 3. Criteria for reflecting potential SSI-topics as suggested by Marks & Eilks (2009, illustrated using doping as an example

Criterion	Description	Example: "Doping"
Authenticity	The topic is authentic, because it is currently being discussed by society. <i>Test:</i> The topic is checked for its media presence in everyday TV, newspapers, magazines, advertising, etc.	The doping debate is not just a Olympic Games event. It represents a constantly repeated topic in newspapers, magazines, political debates and talk shows on TV. The discussion about doping in the fitness and leisure time arena is also constantly mentioned by the media.
Relevance	The topic is relevant, because any societal decision in this area will effect the current or future lives of our students. <i>Test:</i> Scenarios on potential societal decisions are tested to see which options might affect students directly. It is closely connected to the discussion about using substances to increase themselves in the sense of consumption and behavioral choices.	Decisions about allowing doping in professional sports have indirect consequences for most of our pupils. This is the case in terms of their role as potential sport consumers in the media. Setting limits on doping in the areas of fitness and leisure sport might affect students directly. It is closely connected to the discussion about using substances to increase competitive abilities and concentration, for example while studying.
Open evaluation situation with respect to a societal relevant question	Societal evaluation is open and allows for different points-of-view. <i>Test:</i> Everyday life media is analyzed out to see if controversial viewpoints are represented (special interest groups, the media, politicians, scientists, etc.).	Doping limits are constantly debated (inter)nationally within society, politics and sporting clubs. Opinions range from draconian measures of punishment to complete freedom to dope in any area of sports. Equal opportunity and the question of infrequently tested athletes also come into play, as do the questions of an age limit for adults to be allowed to dope or instituting even stricter controls.
Allows for open discussions	This topic can be discussed in an open forum. <i>Test:</i> Thought experiments are used to test opinions stating various points-of-view. The resulting arguments are checked to make sure that no individuals, religious or ethnic groups would feel insulted or be pushed to the fringes of society by their use.	It is possible to discuss the lifting of doping controls in the public forum. Athletes, functionaries and politicians discuss this topic from wide-ranging, controversial viewpoints. The fine line between food supplements, medicines and illegal doping drugs often remains a grey zone. Whether learners dope in fitness or leisure time arenas does not need to be revealed.
Deals with an issue based on sciences (chemistry) or technology	This topic concerns itself with a techno-scientific query, which contains scientific facts and the networks between them at its most basic level. <i>Test:</i> Discourse in the media is analyzed. The question is raised, whether scientific concepts are addressed and either explicitly or implicitly used for argumentation.	The question of punishments for doping must be decided by society. But the point at which taking a given substance becomes doping is not a scientific question; it is defined by panels of sports functionaries. However, the original question is a chemical one. Doping is always a race between two chemists: the developer of possible doping agents on the one hand, and the analyst on the other, without whose evidence a sanctioning of athletes is impossible.

highlighted and compared (Sadler, 2004). The issue must *allow open debate*. This is not a self-evident criterion, since not every SSI can be openly discussed in every social environment. Doping encourages open debate. This can be seen in the open discussions occurring in most societies – at least in the Western portion of the world. Many stakeholders have varying viewpoints and bring them into the debating arena. Positions such as demands for stronger punishments or limited legalization can be supported without making the

participant an outsider. Whether a potential topic can be discussed openly is easily testable by an analysis of the arguments arising in the public debate. These arguments can be evaluated to find whether their use in classroom discussion might insult individual students, marginalize particular religious or ethnic groups, or push some participants into the role of outsiders.

Finally, doping is a *question related to science and technology*. Without question, doping is a scientific question. For the inexperienced person it is very

difficult to draw the line between legitimate food supplements, medicines and illegal doping. To understand and contribute to the debate, a basic knowledge of science and chemistry is essential. Doping can also be understood as a cat-and-mouse game between biochemists as drug designers and analytical chemists as whistleblowers who try to strip dopers of their anonymity. Furthermore, every decision that society or individuals make concerning doping can only be properly made if analytical chemistry can supply a test for detecting such compounds. A prohibition is senseless without a reliable testing method. We can test the science-relatedness of a topic by seeing if the public debate employs scientific facts, techniques, or arguments to support any of the arguments presented by the different sides.

Table 3 summarizes the discussion of all five criteria and gives clear descriptions for each of them, including a testable criterion. The analysis shows how case study topics like doping can be reflected upon to determine their suitability for showing how science interacts with societal decision-making processes in the sense of SSI-based science education.

IMPLICATIONS

The lesson plan on doping described in this paper gives another example of how motivating socio-scientific questions taken from everyday life and society can be for science lessons, if they are authentic, relevant and controversial (Sadler, 2004). This observation confirms a growing number of studies on lesson plans based on the socio-critical and problem-oriented model of science teaching and related concepts (Marks & Eilks, 2009; Sadler, 2011). The societal and individual relevance of the doping debate shows great potential for motivating students to learn science. It also induces pupils to question the societal processes behind political acts of will and decision-making procedures with the help of questions stemming from science and technology.

In this example and by comparison of a whole set of previous cases studies (e.g. Marks & Eilks, 2010), a group of teachers was able to refine the criteria originally suggested by Marks and Eilks (2009) in order to reflect better upon potential topics from everyday life and their potential as socio-scientific issues in science classes. These newly-refined criteria fall principally in line with the respective frameworks and many former test study descriptions on SSI science education (e.g. Sadler 2004; 2011). The current study used a lesson plan on doping to suggest further testable criteria for SSI and collate them with previous studies and examples taken from the literature. These operationalized criteria may help teachers in the classroom and curriculum

developers when selecting and structuring societal issues for SSI-based education.

Because the suggestions presented here have been made as the result of case study research, further research might do well to analyze the influence of the suggested framework. This includes the question of how the suggested criteria directly correlate with student motivation and general skill development. The effect on students' ability to become responsible future citizens is also central and needs further research, since it is one of the primary goals of implementing SSI-based science education (Sadler, 2004; 2011; Roth & Lee, 2004).

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