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Nature of Science in Students' Conceptions of Scientists: A Pilot Study of an "Act a Scientist -Test"

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Abstract

Testing students' of conceptions of science can facilitate their understanding of the nature of science (NOS) and inform their career choices. While drawing-based tests exist, alternative tests are required to measure students' more complete images of science. This pilot study introduces a novel act-like-a-scientist test (ALAST) to capture conceptions about actions associated with science. The pilot was conducted on 28 bachelor-level science students who wrote down scientist actions and mimicked them for peers who identified the actions. The lists of different scientist actions were analyzed using deductive content analysis. Mimicking the actions of scientists was found to represent a broad image of NOS, including epistemic-cognitive, social-institutional and emotional domains of sciences. Moreover, ALAST opens up the possibility for multi-faceted representations, supported communication and deconstruction of stereotypes. Some of the challenges to ALAST include the over-emphasis of science as action, the difficulty of mimicking abstract ideas, and distinguishing individual conceptions. While ALAST was considered successful in this study, more research is needed to develop and validify the test.

Keywords: Nature of science, science conceptions, drama, assessment

Nature of Science in Students' Conceptions of Scientists: A pilot study of an "Act a Scientist - Test"

Developing more authentic conceptions of scientists' work has the potential to promote students' understanding of the nature of science (NOS) and assist them in career choices. Research indicates that students across all age groups possess unrealistic and gendered conceptions of scientists. While such conceptions are formed implicitly, i.e. through media (Losh, Wilke, & Pop, 2008) and science teachers, they can be explicitly addressed with the assistance with tests and reflection such as Draw-a-Scientist Test (DAST) (Finson, Beaver, & Cramond, 1995). However, DAST is criticized for not providing the space to reflect the complete array of students' conceptions (Reinisch, Krell, Hergert, Gogolin, & Krüger, 2017). To provide new, complementary tests to explore inherent conceptions, approaches have been drawn from art (Turkka, Haatainen, & Aksela, 2017). In this study, we piloted an Act-like-a-Scientist Test (ALAST), in which bachelor-level chemistry students express their conceptions by acting like a scientist. This study is part of a design-based research (Edelson, 2002), which aims to develop assessment for the teaching of nature of science (NOS) through drama in science education.

Theoretical Background

Science education aims to promote scientific literacy of students so that they can live with a better understanding of the natural world in the future (DeBoer, 2000). Becoming scientifically literate is based in the understanding of nature of science (NOS) (Dagher & Erduran, 2016). While no consensus of an exact definition of NOS exists, it can be generally characterized by questions such as what science is, how it works, how scientist operates and how science and society interact (McComas, Clough, & Almazroa, 1998). These questions embed a certain image of a scientist, which can be explored to promote students' understanding of NOS. To understand how students' conceptions about a scientists relate to the nature of science, we chose a reconceptualized framework of NOS by Dagher and Erduran (2016) because it provides a holistic representation of the range of work involved in being a scientist and includes specific categories, such as “scientific practices” and “professional activities,” that capture the conception of a science as defined by the actions of a scientist.

Moreover, the theoretical focus of the reconceptualized model of NOS on “science as enterprise” allows the beliefs and values related to science as a career to be better understood. These beliefs and values related to science as a career together with students' beliefs about themselves and their abilities have been argued to influence students career choices (Dick & Rallis, 1991). In other words, students might be more likely to choose a career if they can identify with those within that profession.

Identifying with a scientist can be a challenge for many students. The prevalent conception of a scientist as a middle-aged male, working alone has been documented since the 1950s across age-levels and cultures (Chambers, 1983; Finson, 2002; McCarthy, 2015; Reinisch et al., 2017). This conception stems from diverse sources including media (Losh et al., 2008; Pansegrau, 2008), cultural stereotypes and various social influences such as parents, friends and science teachers (Dick & Rallis, 1991) that emphasize science as academic, strongly intellectual, abstract and decontextualized (Christidou, 2011). So far, these stereotypical conceptions of scientist have been measured with instruments such as Draw-a-Scientist Test.

Draw a Scientist –Test

Chambers' (1983) Draw-a-Scientist Test asks participants to draw their image of a scientist on a sheet of paper. The advantage of DAST is that it is not affected by students' writing skills and can be completed quickly (Finson et al., 1995). These drawings have been analyzed to reveal stereotypical images of a scientist, enumerated in a checklist by Finson et al. (1995) such as a lab coat, eyeglasses, facial hair, symbols of research, symbols of knowledge, technology and scientist captions, male gender, Caucasian, indications of danger, presence of light bulbs, mythic stereotypes, indications of secrecy, indoor setting and middle-aged/elderly. The stereotype varies between groups. 'Facial hair, mythic stereotypes, secrecy, elderly images and danger' were not found in the pre-service teachers' drawings (McCarthy, 2015). Similarly, Reinisch et al. (2017) report that pre-service teachers do not care about appearance of the scientist and recommend dropping ethnicity and adding a neutral gender to DAST questionnaires.

DAST has received criticism. For example, the interpretations of drawings might depend on the relative drawing skills of students (Losh et al., 2008). Reinisch et al. (2017) recognize the difficulties in interpreting the symbols in the drawings and suggest that other sources of data, such as questionnaires and interviews, should be used to verify meanings. Moreover, they suggest that results should be evaluated in the light of the prompt. For example, the prompt "Draw a scientist" implies that students should draw just one scientist, while students may possess several definitions for the word scientist (Finson et al., 1995), or they might be encouraged to draw stereotypes instead of their own conceptions, for the sake of making their drawings more recognizable to their peers (Reinisch et al., 2017). In addition, the simple prompt might encourage students to focus on the appearance of a scientist, making it difficult to capture the nature of science aspects embedded in the actions of a scientist. Farland-Smith, Finson, Boone and Yale (2014) modified the prompt to emphasize the appearance, location and activities of a scientist, therefore enabling a broader representation of science.

Recognizing the criticism of DAST we sought complementary assessment of students' conception of a scientist. We drew from art integration pedagogic methods (Turkka et al., 2017) and developed a pilot test based on drama to explore scientist actions.

Expressing Internal Conceptions with Drama

Drama strategies have been suggested as a teaching method to learn about science concepts, the nature of science and interaction of science and society (Ødegaard, 2003). Dorion (2009) reports that drama enables participants to communicate abstract meanings multimodally, using non-verbal means such as gestures, space, movement and body language. Students' gestures have been suggested to help the teacher to recognize pre-articulate ideas, distinguish in-between explanations and descriptions, display a novelty of ideas and facilitate idea construction (Scherr, 2008). Drama strategies such as improvisation and mimicking provide opportunities for students to improvise movements and gestures to reveal conceptions and reconstruct these conceptions. Moreover, drama strategies can encourage students to "act like a scientist" to momentarily adopt not only the thoughts but also the emotions of a scientist (Turkka & Aksela, in review), facilitating empathy towards scientists and through that a rich and personal way of understanding science (Duveen & Solomon, 1994). While science is often considered devoid of emotion, understanding of emotions in science can contribute to the understanding of the nature of science. Emotions, for example, are irreducible part of personal motivation for science and social fabrication of science (Barbalet, 2002). Finally, in comparison to drawing how a scientist looks from a distance, improvising a scientist's actions could provide more immediate and emotional expression through an inside-out perspective, therefore revealing more implicit thoughts and assumptions and students' authentic conceptions of a scientist.

Methodology

The goal of this study is to provide a proof of concept for the Act-like-a-Scientist Test (ALAST). This pilot study is part of a larger research program aiming to develop formative assessment of teaching about nature of science with drama in science education. The questions that guided this research were:

- What aspects of nature of science can be expressed by mimicking actions of scientist?
- What are the advantages and disadvantages of ALAST?

In ALAST, students are prompted to "imagine what a scientist does" and individually write down as many relevant actions as possible. Then a game is introduced to the students, whereby the students mime the actions on their list to a group of peers, who to try to recognize them. When a peer recognizes what action is being acted out, s/he shouts it out and the student who is acting can move to the next word on his/her list if their action has been correctly identified. The students take turns acting out their list of actions. The student who acts out the most words on his/her list in two minutes time will win the game. ALAST is introduced as a game to make the test more engaging and to reduce time to think in order to capture more immediate ideas about science. Afterwards, a moderator of the game can guide reflection about which types of NOS-conceptions appeared in the game.

A pilot of ALAST, as described above, was conducted with 28 bachelor-level chemistry students organized into test groups of seven people. One of the groups were studying to become science teachers. The students at this level have not had any education about NOS in the university and were not introduced to the NOS-framework before the test but were briefed on it afterwards during the reflection. The material gathered for this study consists of the individual word lists of the students. The words in these lists were marked if they were successfully recognized by peers. The original lists were in Finnish and were translated to English.

The material was analyzed with deductive content analysis (Mayring, 2014). The category system (Table 1) is modified from a reconceptualized model of NOS (Dagher & Erduran, 2016), which distinguishes between epistemic-cognitive and social-institutional dimensions of nature of science.

We introduce an additional emotional domain to the framework, following suggestions from a history of science framework that suggest that teaching empathy can be critical to helping students connect with and deconstruct the culture of science (Güney & Seker, 2012). While the existing framework was well-suited to capture conceptions of the exterior worlds of a scientist, the emotional dimension is introduced to capture more humanistic conceptions students have about what it is like to be a scientist.

Table 1

Main categories

Cognitive-epistemic	Social-Institutional	Emotional
Scientific practices [NOS1] Aims and Values [NOS2] Methods and methodologies [NOS3] Scientific knowledge [NOS4]	Professional activities [NOS5] Scientific ethos [NOS6] Social certification [NOS] Social values [NOS8]	Emotional experiences [EMO]

The reconceptualized model of NOS introduces scientific practices and professional activities as ways to understand science as action. For the purposes of this study six other categories were modified into form of action. The coding of the "scientist actions" to all of these categories together are presented below in Table 2 together with anchoring examples found in the sample.

Table 2

Coding scheme

Code	Definition of category (modified from Dagher & Erduran (2016)).	Anchor examples
NOS1	Actions related to scientific practices such as observing, asking questions, gathering and	Observes, researches, documents, compares, boils

	classification of data, designing an experiment, creating models and theories, creating hypothesis	
NOS2	Actions that directly refer to aims and values of science such as consistency, objectivity, simplicity and novelty. Examples would be ensuring objectivity, inter-coding, calculating reliability	Ensembles big pictures, reforms, rejects
NOS3	Actions that refer to methods and methodological choices linking values and practices such as choosing appropriate methodologies to ensure validity and reliability	Revises, repeats, verifies, pilots
NOS4	Actions related to using the entities of scientific knowledge such as modelling and theoretizing (in comparison to scientific practices that create this knowledge)	-
NOS5	Professional activities such as attending a meeting, applying for funding	Attends meetings, sits
NOS6	Scientific ethos in scientist actions such as criticizing and respecting the nature	Calls into question, criticizes, toadies, plots,
NOS7	Actions that relate to Social certification and dissemination of scientific knowledge such as peer-reviewing and publishing	Publishes knowledge, networks
NOS8	Actions that relate to social values of scientist actions such as creating solutions for problems or innovations	Innovates, benefits, produces value

EMO	Actions that describe emotions or affections related to science or emotions of a scientist	Gets confused, gets frustrated, is surprised, fails, succeeds, hesitates, fusses, plays

Results

In the study, 194 scientist actions were coded as representing one of the emotional-cognitive, social-institutional and emotional categories. A total number of 89 of the 194 were coded as distinct actions after considering crossovers in each individual list. The category frequencies are represented in Table 3.

Table 3

The frequency of scientist actions representing the different areas of NOS

	Categories	**Different actions**	**Recognized by peers**	**Unrecognized by peers**	**TOTAL**
Epistemic-cognitive	NOS1	23	70	22	92
	NOS2	6	1	5	6
	NOS3	4	2	3	5
	NOS4	0	0	0	0
	TOTAL	33	73	30	103
Social-institutional	NOS5	30	40	20	60
	NOS6	6	2	6	8
	NOS7	3	3	0	3
	NOS8	4	2	2	4
	TOTAL	43	47	28	75
Emotional	EMO	13	6	10	16

TOTAL	89	126	68	194

Epistemic-cognitive actions were the most frequently observed (N=103). These included 33 different scientist actions that students generated. The three most frequently actions were researching, thinking and experimenting all of which represented Scientific Practices (NOS1). The actions related to the sub-categories of Aims and Values (NOS2) and Methods and Methodologies (NOS3), such as reforming or revising, were rare. No actions related to Scientific Knowledge (NOS4) were found in the sample.

While social-institutional actions were less frequently written in students' papers (N=75), these consisted of a wider variety of different actions (N=43) than epistemic-cognitive actions (N=33). The most frequent epistemic-cognitive category was professional activities, e.g. writing and discussing (NOS5). The less frequent social-institutional sub-categories were Ethos of Science (NOS6), Social Certification and Dissemination (NOS7) and Social Values (NOS8). Within these, all of the NOS7 actions were successfully recognized by peers.

Emotional actions were less frequent (N=16) than the other main categories. The actions within this category were more often unrecognized by the participants than in the other categories. The actions that occurred more than once within this category were "wondering," succeeding and getting interested.

The Possibilities and Challenges

Table 3 illustrates some of the possibilities of ALAST. First, a total number of 89 different actions indicates that ALAST can provide a broad representation of scientist actions and not just one-sided conception of a scientist. Second, the majority of the written actions were also recognized, indicating that students can communicate actions to their peers through mimicking. Third, the imbalance in recognizing epistemic-cognitive vs. social-institutional scientist actions indicates that a certain stereotype exists in the group, which allows students to reflect on that stereotype.

Similarly, Table 3 illustrates some of the challenges related to ALAST. First, the categories that were not based on actions were less represented, indicating that the prompt needs to be developed further to enable more detailed reflection. Second, there were categories which were rarely communicated to others, indicating that there might be certain type of abstract actions which are challenging to communicate through mimicking. Third, Table 3 represents only groups shared conceptions. From the current design of ALAST, it is meaningless to quantitatively assess individuals conceptions of science from the number of successfully communicated scientist actions, because this amount is likely to depend on mimicking abilities as well as students' abilities to read each others' body language.

Conclusions and Discussion

The NOS Scope of ALAST

The occurrence of both epistemic-cognitive and social-institutional actions indicates that the ALAST has the potential to capture different aspects of NOS through scientist actions. Within our sample, the more frequent scientist actions were epistemic or cognitive, such as experimenting or thinking. The epistemic actions align with the findings of Reinisch et al. (2017) who report that activities that students draw in modified DAST are significantly related to inquiry. The ALAST has the potential to complement this by exploring cognitive actions, which have been only symbolically represented in drawing (e.g. light bulbs above scientist heads). Mimicking enables dynamic representation of what is happening beyond one static frame, as the case with drawings. Moreover, emotional expressions have not been focused on with DAST, but appeared without specifically being prompted for in ALAST. The possibility to express emotions contributes to the ability to test conceptions of a scientist more broadly. Being able reflect on scientist emotions after the test opens up further possibilities to promote understanding of the science as a human endeavour (Dagher & Erduran, 2016). While Dagher and Erduran (2016) do not specifically emphasize the emotions in the scientific process, they are irreducible parts of both scientific motivation and the social fabrication of science and can broaden the understanding of science (Barbalet, 2002). Finally, the sub-categories that were not directly "action-based" were rare, such as scientific knowledge, which was not found in the sample. In principle, scientist actions, such as theorizing or modelling could have covered scientific knowledge area of NOS. More research is needed to see if this type of actions can be captured with ALAST.

The Possibilities of the ALAST

The results reveal the possibilities of ALAST. First, the 89 different actions written in the list of actions indicate that ALAST can provide a multifaceted image of scientist. Second, the high ratio of successfully identified scientist actions point toward supported communication through mimicking. Even rather abstract cognitive actions such as analyzing were recognized by peers. This aligns with Dorion's (2009) conclusions that nonverbal gestures and movement support the communication of abstract ideas in science. The successes of communication through mimicking could be explained in part by early acquisition of the motor-sensory skill required for ALAST, which is based on imitation, a cognitive exercise practiced by newborns (Meltzoff & Moore, 1983). However, the "easiness" of communication with ALAST cannot be taken for granted in every case, because acting in front of one's peers can be emotionally challenging for some of the students (Turkka & Aksela, in review).

A third possibility has to do with deconstruction of a science stereotypes. In this study the students emphasized science as epistemic-cognitive actions, which aligns with the stereotype of a science as academic, and strongly intellectual practice (Christidou, 2011). This enabled an instant in-group reflection on this image and offered possibilities to discuss alternative images of science. A future possibility is to mimic alternative images of a scientist after this type of reflection in order to facilitate the construction of new ideas (Scherr, 2008).

The Challenges of the ALAST

The results indicate challenges to employing ALAST. The lack of representation of sub-categories not originally based on action indicate an imbalanced emphasis on science as action. The analytical framework needs to be developed further to understand how these actions relate to other aspects of NOS. The imbalance arises from the difficulty to infer the meaning of an action without a broader context. A similar problem is recognized in DAST: it is difficult to analyze polysemous meanings and additional clarifications are always needed (Reinisch et al., 2017). One future possibility to develop ALAST would be to experiment with mimicking specific situations or contexts based on the NOS categories. Another modification would be to mimic in pairs, or in a group, to encourage acting out science as social interaction.

Second, some of the abstract actions such as reforming or revising were not identified by peers, which indicates a challenge in representing certain abstract NOS ideas. More complex actions require more mimicking of a context, which might require more time to think. Mimicking challenging words could be beneficial because it would require students to think what is at the core of these actions in order to communicate them for their peers.

Third, the acting is done within and for the group, and it is meaningless to quantitatively assess individuals level of NOS-understanding from the results. The number of successfully identified actions are very likely to tell more about individuals' ability to act and read body language, rather than the individuals' informed views of science. Doing well in the mimicking encourages students to specifically express stereotypes of a scientist, instead of one's own conceptions. Finally, students who mimicked the actions on their list later in the game had the opportunity to see how their peers mimicked particular actions, making it easier to act out those concepts by relying on the same actions employed by their peers if those actions were also on their lists. That would also affect the amount of time it takes them to successfully act out an action if they save the time of thinking about how to act a given action out, and their partners save the time of having to uniquely identify that action.

Implications

ALAST is an novel way to measure students conceptions of a scientist. ALAST was found to illustrate scientist emotions, which creates prospective ground for the development of empathy and, through that, a more personal understanding of science (Duveen & Solomon, 1994) (Duveen & Solomon, 1994). Moreover, engaging students with ALAST enables a teacher or the researcher to ask a range of fundamental questions that help students to reflect their own NOS conceptions. This makes ALAST a valuable test for teacher education courses dealing with NOS. Some exemplary questions would be: which words were difficult to mimic and why; do the mimicked scientist actions represent your own ideas about science; what aspects of science are missing?

While the pilot of ALAST was successful, more research is needed to validate and develop the test. For example, video recordings are needed to analyze the mimicked actions in detail to analyze if the gestures illustrate more hidden aspects of the participants inherent conceptions of the nature of science, than mere written scientist actions (see i.e. Scherr, (2008). Finally, we recommend science teacher educators and researchers introduce ALAST as an alternative and engaging version of a test of students' conception of a scientist.

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