Advances in Engineering Education

SUMMER 2020

Engineering Ethics as an Expert-Guided and Socially-Situated Activity

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ABSTRACT

Engineering ethics education typically focuses on decisions by individual engineers and case studies of disasters. This does not reflect the everyday decisions that practicing engineers must make, and neglects the fact that most engineers work on teams rather than alone. The focus on safety and disaster prevention leaves little time for discussing pervasive social impacts of engineering and technology. Our research seeks to fill these gaps by determining how ethical decision making occurs in team settings, how it can be influenced by ethics-focused team members, and to what extent a social context influence consideration of social impacts.

Over three years, we observed ethics discussions among teams of engineering students. First, we observed undergraduates during their Capstone Design project. We contrasted typical teams and teams with an additional team member trained and educated in engineering ethics. Second, we observed university research laboratory groups composed of undergraduate students, graduate students and post-docs in their spontaneous and regular conversations. Data analysis suggests that engineering students have a narrow understanding of engineering ethics, and that their explicit and implicit understanding can be in conflict. We also observed that an engineering expert can improve the breadth and depth of conversations. We also observe that engineering students rarely—if ever—discuss ethical or social implications of their work during routine activities. This also points to the benefits of facilitated discussions.

Key words: Professional ethics; Teams, team dynamics; Ethnography, Observation, Survey

INTRODUCTION

In the late 1990's and early 2000's, there were a series of notable investigations into the number of universities that required instruction in engineering ethics and into the nature of that instruction [1], [2], [9], [3]. The earliest study showed that almost 68% of the 254 schools surveyed had no ethics requirement for students [1]. Around the same time, the Accreditation Board for Engineering and Technology (ABET) adopted the Engineering Criteria 2000 (EC2000) requirements, which explicitly included professional and ethical responsibility in curriculum necessary for accreditation.

There is a surprising lack of follow up surveys or investigations, so it remains unclear what distribution of schools currently have formal instruction in engineering ethics and responsibility. Nevertheless, it is clear that many engineering schools require a formal course in engineering ethics, and subsequent research has focused on the nature and efficacy of individual courses. A variety of alternative pedagogical models have been explored in research, but so far, none has seen widespread adoption. Shaped by the ABET EC2000 standards, such courses often focus on the content and application of ethics codes and help meet government-imposed professional licensing requirements [2], [4], [5], [6]. Many courses in engineering ethics focus on ethical and legal principles, codes, and skills for recognizing, reflecting on, and resolving ethical issues [7], [8], [9], [10]. Ethics education frequently involves traditional classroom lectures and discussions led by outside ethics experts or "ethics across the curriculum" initiatives. The effectiveness of this approach remains a matter of open debate [2], [11], [12].

We have observed that technical content receives the vast majority of focus in engineering curriculum, while humanitarian good or moral responsibility are given little formal consideration. Moreover, ethics problems are often treated like design problems to be straightforwardly solved, rather than teaching engineers to think in value-driven modes [9]. Ethics requires not only theoretical knowledge but also practical wisdom, including the ability to make decisions in particular contexts [15]. However, many ethics courses organize instruction around case studies, especially those involving major disasters [2], [16], [17], [18]. Such cases are often very different from the everyday ethical reflection faced by engineers [19].

The first motivation of our research is the observation that the typical engineering ethics education described above strives to ensure that *individual* professional engineers possess ethical responsibility. But most professional engineers will work on team-based projects. Thus, we are led to the research question: how are decisions about ethical and social issues made in teams of engineers, rather than by lone individuals?

Our second motivation stems from a curious tension we perceive in the traditional approach to ethics in engineering. The second "Fundamental Canon" of the National Society of Professional Engineers (NSPE) "Code of Ethics for Engineers" councils engineers to, "Perform services only in areas of their competence" [20]. Many professional engineering societies have similar statements (e.g., [21], [22], [23], [24], [25]) in their ethical codes. Engineering ethics is an area of competence that requires training. Can we say that engineers are qualified to engage in ethical reasoning, given that ethics training comprises a small portion of their education [26], [28]? If an engineer should not undertake and perform work for which he or she is not qualified, it would seem that engineers should very rarely undertake ethical decision making [44]. Internalizing this tension may be a primary reason that engineering students appear reluctant to consider ethical and social ramifications of their work. Therefore, we are led to the research question: can having a team member with the specific responsibility for, and some training in, engineering ethics influence or alter the group's decision making, and, if so, how? We pause to note that some vexed philosophical issues about the relation of expertise and ethics arise from this line of thinking, but we have chosen to focus here primarily on the effect of introducing actors with the *role responsibility* for ethics.

The study discussed here investigated ethical reflection in undergraduate and graduate engineering students conducting team projects. Specifically, we observed teams discussing the ethical issues surrounding their projects and collected a variety of ethnographic data. We also observed research labs and provided an opportunity of facilitated ethics discussion to their members.

STUDY METHODOLOGY

Participants

The project focused on two groups of engineering students. The first group was senior design project teams, composed of undergraduate engineering students. The second was university research laboratory groups, consisting of graduate and undergraduate students. All participation was voluntary, and the study was conducted under IRB approval.

Senior Design Teams

32 undergraduate senior engineering teams participated in our study. All students were enrolled in the senior design project (SDP) course—a two-semester course sequence, during which senior engineering students work on a large-scale project, often sponsored by and benefitting a company. The SDP course requires students to document and report on their design progress. The course culminates in a final report and poster presentation that summarize their design, as well as

presentation of a prototype. Each team is required to consider and report on the ethical ramifications of their project. During the course of our study, we tracked 16 teams over the course of two semesters (F14 and S15) and the remaining 16 teams for one semester only (four teams in S14 and twelve teams in S15).

Ethics Advisors

62 students total from several semesters of philosophy of science and technology courses, typically divided into teams of 2 or 3, participated in this study. Their coursework included a significant focus on ethics and values in science and engineering. They learned about the NSPE code of ethics and discussed it in class. In the main arm of the study, ethics advisors received training on how to advise engineering teams, which focused on asking open-ended questions that encouraged ethical deliberation and the multiplication of options for responding to socially fraught questions.

Research Laboratories

We recruited a total of 50 (11 female, 27 male, 12 undeclared) graduate, post-doctoral, and undergraduate students involved in research projects carried out in three engineering laboratories at the UT Dallas campus and in two engineering laboratories from partnering institutions.

Materials

VOSTS (Views on Science-Technology-Society) Survey

VOSTS (Views on Science-Technology-Society) is an item pool that consists of multiple-choice items to measure a responder's views on socio-scientific and/or socio-technological matters [29][30][31][32][33]. Multiple-choice statements in the VOSTS questionnaire are based on accumulated answers from previous survey responses, which represent various perspectives. We constructed the survey questionnaire using VOSTS items and modified them to focus on engineering ethics. Our modified VOSTS consisted of 25 prompts: twelve of which reflected social responsibility (referred to later as S, for examples see Appendix 1), seven reflected practical responsibility (referred to later as R; practical responsibility refers to health, safety, and legal regulation issues; c. f. Appendix 1), and six reflected ethics within professional (referred to later as P; professional responsibility refers to practice standards defined by professional community of engineers; c. f. Appendix 1) aspects of engineering. Each prompt was followed with seven statements reflecting views on engineering ethics that varied in their complexity (see Appendix for examples of items and scoring). The participants' task was to choose the statement that reflected their views on an engineering issue described in a given prompt. The individual scores could fall anywhere between 25 points at the minimum (simplistic understanding of engineering ethics) to 75 points maximum (complex understanding of engineering ethics). The VOSTS survey was administered to members of 16 SDP teams that completed two semester courses (F14 and S15). Each participant was requested to read prompts about ethical and social responsibility in engineering and choose an answer reflecting their attitudes towards the prompt. The data were collected before starting SDP team discussions of ethics and after the teams completed multiple discussions.

Toolbox Protocol

To facilitate ethics discussions among the members of the participating research labs, we applied the Toolbox dialogue protocol [34][35][36]. This protocol consists of a survey instrument and a dialogue-based workshop. We provided an online pre-discussion survey that contains specific questions organized around three open-ended core questions: 1) How do values influence engineering design and research? 2) To what extent are engineers responsible for the harm that might result from their designs and products? 3) To what extent are engineers concerned with the potential effects that might result from their designs and products? Each section includes six queries, with responses following a Likert scale. The queries and responses are designed to shed light on the three primary questions. The survey result was used to obtain a group profile for the purposes of structuring the Toolbox dialogue.

Procedure

Senior Design Teams

Each SDP team was randomly assigned to either intervention or control condition. A total of 14 SDP teams were assigned to the intervention condition, in which one or more *ethics advisors* facilitated the SDP team members' discussions on ethics issues related to their project. As previously mentioned, the ethics advisors were students enrolled in a philosophy of science and technology courses on campus and received training on ethics and values in engineering and design, as well as specific training on the NSPE ethics code and advising engineers. That said, these students were not "ethics experts," just as the engineering students are not yet "engineering experts." However, their interaction provides both a model of interacting experts and a unique pedagogical approach. The peer ethics advising strategy is based on the *peer instruction method* [48]. Peer instruction is known to improve students' conceptual understanding as well as problem-solving, and we expect that the presence of peer ethics advisor will help SDP teams experience cross-disciplinary collaboration to resolve ethics issues, which often occurs in real life engineering practices.

The remaining 18 teams held discussion without an external ethics advisor. We observed and video recorded discussions from 10 randomly selected teams from both conditions. Each discussion was recorded in its entirety; the discussions typically lasted between 20 and 40 minutes.

For the SDP teams that completed two semester courses, we administered the VOSTS surveys at the beginning and at the end of each data collection period to compare their pre and post intervention responses.

Research Laboratories

We conducted five group discussions, three from research labs at UT Dallas and two from partnering institutions. Before the discussion, the online Toolbox survey was given to lab members. We analyzed the participants' answers only insofar as they provided the profile of their converging and diverging views on values in engineering and to initiate and facilitate the group discussion. One of our research team members guided the discussion as a facilitator, and another member of the research team observed the discussion and took field notes. The facilitator guided a discussion based on the Toolbox protocol using the pre-survey results. All discussions were video-recorded.

Data Analysis

We collected and analyzed two types of data: 1) ethnographic data on ethical decision making and moral judgment, 2) the VOSTS survey data on understanding of ethics. Ethnographic data was gathered from field notes from observations and videos. Video data was transcribed and, along with the field notes, was analyzed through micro-scale discourse analysis based on cognitive ethnography [37][38][39]. The VOSTS data were analyzed to see complexity of students' understanding of engineering ethics.

RESULTS

Complexity of SDP Students' Understanding of Engineering Ethics

Recall that the VOSTS survey was administered to 16 SDP teams, once at the beginning of their first semester (before they discussed ethics as a team) and once at the end of their second semester. Out of those 16 SDP teams, nine were assigned to the intervention condition (discussion with "ethics advisors"), and seven to the control condition (discussions without ethics advisors). The most simplistic responses in the VOSTS questionnaire included a single reason, cause, or effect in response to the prompt, while the most complex ones encompassed multiple perspectives or factors. Engineering ethics issues are usually multifaceted and include diverse and complex aspects. If students were aware of this, they would be expected to choose the answer option that included multiple perspectives in response to the prompt. We realize that the complexity of understanding may not directly indicate the students' comprehension of engineering ethics; it may, however, indicate students' awareness of the complex nature of engineering ethics.

A total of 43 participants completed both the pre and post VOSTS surveys. After removing two outliers, 41 cases—21 in the intervention condition, and 20 in the control condition—were entered into the final statistical analyses. Overall, the students in SDP teams assigned to the intervention condition demonstrated similar levels of complexity of understanding of engineering ethics as did the students in SDP teams in the control condition, regardless of the VOSTS subscale. Therefore, the results discussed below pertain only to the differences in complexity between pre intervention and post intervention assessments.

Table 1 shows descriptive statistics for the pre and post VOSTS survey results, and, as it is evidenced, the means for VOSTS total and for the VOSTS subscales decline from the pre-intervention to the post-intervention survey.

Further statistical analyses revealed that this decrease of the overall complexity of understanding of engineering ethics (the VOSTS total means) is statistically significant (M = 4.14, SD = 9.44, $t(40)$ = 2.81; p = .008). Looking in greater detail, while there were not any significant changes in the complexity related to social responsibility from pre- to post-intervention surveys, the complexity of understanding professional and practical ethical issues did decrease (VOSTS Prof: M = 1.46, SD = 3.07, $t(40)$ = 3.04; p = .004; VOSTS P: M = 1.31, SD = 3.62, $t(40)$ = 2.32; p = .025). One possible explanation is that as the students moved from the design phase of their projects (first semester) to actually building the prototypes (second semester), their focus shifted from broader (and possibly more complex) issues pertaining to design and professional conduct, to a narrower view focusing on technical issues.

Our ethnographic observations of some of the SDP teams (discussed in greater detail in the subsequent section) corroborates this tendency. For example, the SDP teams who partnered with ethics advisors discussed ethics issues in broad contexts at the beginning of their projects and

Table 1. Descriptive statistics for pre and post intervention VOSTS totals, including Social (S), Practical (R), and Professional Responsibility (P) subscales (N = 41).

Pre-Intervention						Post-Intervention					
Variable	Mean	Std. Dev.	Std. Error Mean	Min.	Max.	Variable	Mean	Std. Dev.	Std. Error Mean	Min.	Max.
VOSTS Tot.	49.22	7.95	1.24	25.00	65.00	*VOSTS Tot.*	45.07	10.28	1.60	22.00	68.00
VOSTS S	24.10	4.58	.71	12.00	33.00	*VOSTS S*	22.73	6.12	.95	12.00	34.00
VOSTS R	14.95	3.52	.55	7.00	20.00	*VOSTS R*	13.63	3.29	.51	5	21.00
VOSTS P	10.17	2.72	.42	5.00	14.00	*VOSTS P*	8.71	2.76	.43	5	14.00

gradually shifted the focus of their discussion to narrow and more technical aspects. It seems that the nature of the design projects pushes students to focus on specific aspects of engineering ethics.

Implicit and Explicit Understanding of Engineering Ethics in SDP Student Teams

We found that there was multi-layered understanding of engineering ethics among student teams. What the SDP team explicitly stated about engineering ethics was often not consistent with what the team implicitly demonstrated by choice of words, gestures, and attitudes during the discussion [26]. Participating SDP teams all demonstrated similar explicit understanding, focused on a narrow understanding of engineering ethics, such as preventive ethics and technical responsibility. However, some SDP teams showed implicit understanding of social implications or social responsibility [40]. For example, one SDP team clearly empathized with the eventual end user of their project. They used first person pronouns when discussing how the user would feel, i.e., they spoke as if they were the user. Their implicit understanding of ethics led them to design choices that would improve the experience of the user.

Another team was faced with potential safety risks if the product was misused. They initially suggested a solution that reflected their implicit understanding, and they tried to develop technical decisions to support this solution [40]. This process was similar to how intuitive ethics works in moral judgment [40], [42]. According to Haidt, reasoning does not typically generate or alter judgments. Although the team's implicit understanding influenced the whole process of the discussion, it was the team's explicit understanding that ultimately determined the decision-making. [43]

Role of Ethics Advisors in Ethics Discussion among SDP Student Teams

We found that the SDP team with ethics advisors tended to bring diverse ethics issues to the discussion, and when they discussed a certain issue, they initially tended to discuss it in a broad context, gradually narrowing it down to the specific cases [47]. Ethics advisors could also provide diverse perspectives to enrich the ethics discussion by asking questions from a different point of view or reminding of unexpected social impacts. Notably, this benefit only occurred when the ethics advisors and the SDP team members were in a collaborative environment [45]. When the ethics advisors and the SDP team understood each other's task and situation, a collaborative environment was established. Lack of this understanding created an uncooperative environment that did not help the discussion. For example, we video-recorded five SDP team discussions with ethic advisors; three of those teams showed better collaborative environment than the other two teams, because those three teams and their ethics advisors were well-prepared about the nature of the SDP projects and their task in ethics discussions. Teams without ethics advisors tended to discuss ethics issues in a narrow context, showing no changes or difference in the scope of issues over successive discussions.

Ethics Discussions in the Engineering Labs

When observing laboratory groups, we witnessed many lively discussions about research topics, but discussion of ethics or social implication issues did not voluntarily or spontaneously occur during observations [46]. For example, in the medical device development project, which had the potential to directly affect human subjects, the issue of ethics or social responsibility was rarely discussed. On the other hand, other issues such as interdisciplinary collaborations between engineering and medicine were frequently discussed. Nevertheless, most of the lab members were willing to discuss ethics when there was an opportunity like a Toolbox protocol-based discussion. During the Toolbox discussion, participants showed that they have sound opinions about engineering ethics, but their understanding of it was rather narrow. For example, a common opinion was that any social implications of engineering ethics are “mostly up to the managers,” i.e., the managers would have a final say in what social implications of engineering ethics are worth considering or acting upon. When lab members were asked about who might be affected by their research outcomes, they did not mention indirect outcomes or broad social impacts in their answers. They seemed to have never thought about or discussed indirect outcomes or social impacts. When prompted to see broad ethical or social context, however, most of them answered that their research outcomes will eventually benefit people.

CONCLUSIONS AND FUTURE DIRECTIONS

The results of VOSTS questionnaires and ethnographic observations provide evidence that as the teams of engineering students move along the design timeline, their focus shifts from awareness of the multifaceted nature of engineering and professional ethics to more specific and technical aspects of their projects. Moreover, the ethnographic observations suggest that the *explicit* understanding of engineering ethics the student teams share is rather narrow and limited to technical aspects of the design. It is likely, then, that such understanding may be learned through, or is a byproduct of, explicit instruction. Additionally, we noted that the teams we observed showed different dynamics between implicit and explicit understanding of engineering ethics. This suggests that students bring a broad range of intuitions about social responsibility that could provide a potential resource for engineering ethics education and ethical practice. Furthermore, ethics advisors can improve the quality of ethical reflection by raising a greater variety of issues, and they can also modulate the discussion by guiding teams to see the broader social context or to consider diverse perspectives. This is not because the advisors had some expertise in *being* ethical, nor they were morally superior individuals, but rather because they had specific training in engineering ethics and, more importantly, the *role responsibility* for raising ethical questions about the project. Just as the SDP students are not fully trained and credentialed engineering experts, the ethics advisors are not fully trained ethics experts, but their interaction provides a valuable model for the educational simulation of SDP. As far as engineering labs are concerned, the results suggest that there are not many opportunities for lab members to discuss ethical or social aspects of their project at hand, so situated modulation may be helpful to facilitate ethical or social considerations in engineering research labs.

Based on the results presented above, we suggest a multi-stage, situated approach to engineering ethics education. First, students need to be exposed to diverse perspectives regarding ethical and social issues in engineering and to have more opportunities to discuss them. Second, students need to have practical learning experience of ethical decision making tied to their actual work, not simply reviewing ethical decisions in separate settings focused on extreme cases. Finally, collaborative approaches involving ethics advisors in some form could improve the reasoning of engineering teams in coursework or the lab. This general approach implies a few pedagogical proposals for engineering programs in higher education, primarily that student project teams should include team members with an explicit role responsibility for considering ethical and social issues.

These suggestions for future pedagogy are based on results of a small, primarily qualitative study. Future research in this area should interrogate these results by looking at a wider variety of engineering fields at a wider variety of institutions. The specific trends discovered in this study should inform future experimental designs that can investigate the generalizability of those trends. Future qualitative or mixed-methods work is needed to investigate the sources of engineering students' ethical understanding and the influence of both formal and informal educational environments on the students' sense of their own ethical responsibilities. Finally, future research could develop an intervention protocol for ethics advisors akin to the Socio-Technical Integration Research (STIR) protocol [50], as well as teaching modules on engineering ethics, based on these findings and test their efficacy.

ACKNOWLEDGEMENT

We would like to thank our UT Dallas student research assistants (now alumni) Kenneth Huynh and David Oluwole, for their help with early data coding and data analyses in the study reported in this article. Kenneth Huynh transcribed video recordings of Senior Design Project teams discussing the ethical ramifications of their projects. David Oluwole's contribution was assisting in data entry, data coding, and statistical analyses.

The study reported here was supported by NSF Award EEC-1338735, *Engineering Ethics as an Expert Guided and Socially Situated Activity*, September, 2013 –August 31, 2016.

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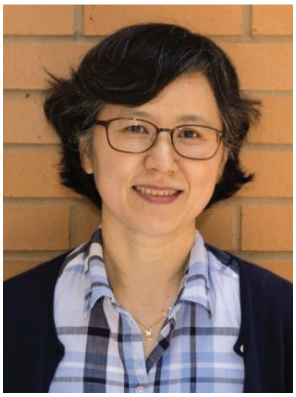

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Appendix 1. Examples of adapted VOSTS questionnaire prompts with answer choices, ethics classification, and level of complexity.

Ethics Classification	Questionnaire Prompt	Answer Choices	Complexity
Social Responsibility	Most engineers are concerned with the potential effects (both helpful and harmful) that might result from their designs and products.	1. Engineers only look for beneficial effects when they design things or when they apply their design to make the products.	Simplistic (1)
		2. Engineers are most concerned with the possible harmful effects of their design and product, because the goal of engineering is to make our world a better place to live in. Therefore, engineers test their design in order to prevent harmful effects from occurring.	Simplistic (1)
		3. Engineers are concerned with all the effects of their design and product because the goal of engineering is to make our world a better place to live in. Being concerned is a natural part of doing engineering because it helps engineers understand their design and product.	Simplistic (1)
		4. Engineers are concerned but they can't possibly know all the long-term effects of their design and product.	Simplistic (1)
		5. Engineers are concerned but they have little control over how their design and product are used for harm	Simplistic (1)
		6. It depends upon the field of engineering. For instance, in biotechnology, engineers are highly concerned. However, in nuclear power or in military research, engineers are least concerned.	Complex (3)
		7. Engineers may be concerned, but that doesn't stop them from making design and product for their own fame, fortune, or pure joy of doing it.	Complex (3)

Appendix 1. (Continued).

Ethics Classification	Questionnaire Prompt	Answer Choices	Complexity
Practical Responsibility	When engineers come upon what *might be* a dangerous idea or product in their work, they actually do inform the public authorities, no matter if it means losing their job or being demoted.	1. Engineers do tell the authorities because an engineer's job is to help the public, not harm them.	Simplistic (1)
		2. Engineers do tell the authorities because engineers want to avoid the severe consequences if something goes wrong. If the public finds out, there could be lawsuits.	Simplistic (1)
		3. It depends on the engineer and the danger. Some engineers tell the authorities because of the dangerous possibilities. Others do not because they need their job to support a family or to become successful.	Complex (3)
		4. Engineers do not, in good conscience, tell the authorities because engineers do not want to lose their jobs or frighten the public. Instead they conceal the idea or destroy the product so no one would know or get hurt.	Simplistic (1)
		5. Engineers do not tell the authorities because engineers want to keep their jobs and make money, even if the public is in danger.	Simplistic (1)
		6. It's not the engineer's responsibility. It's the company's responsibility. Engineers discuss the dangers with the company, and then the company tells the authorities.	Simplistic (1)
		7. Nobody knows. We hear about the engineers who do tell the authorities. We don't hear about the secrets kept from the public.	Simplistic (1)
Professional Responsibility	When engineers disagree on an issue, they disagree mostly because they do not have all the facts. Such professional opinion has nothing to do with moral values (right or wrong conduct) or with personal motives (personal recognition, pleasing employers, or pleasing funding agencies).	1. Disagreements among engineers can occur, because not all the facts have been discovered. Professional opinion is based entirely on observable facts and scientific understanding.	Simplistic (1)
		2. Disagreements among engineers can occur, because different engineers are aware of different facts. Professional opinion is based entirely on an engineer's awareness of the facts.	Simplistic (1)
		3. Disagreements among engineers can occur when different engineers interpret the facts differently (or interpret the significance of the facts differently). This happens, because of different scientific theories which engineers apply, not because of moral values or personal motives.	Medium (2)
		4. Disagreements among engineers can occur mostly because of different or incomplete facts, but partly because of engineers' different personal opinions, moral values, or personal motives.	Complex (3)
		5. Disagreements among engineers can occur for a number of reasons — any combination of the following: lack of facts, misinformation, different theories, personal opinions, moral values, public recognition, and pressure from companies or governments.	Complex (3)
		6. Disagreements among engineers can occur when different engineers interpret the facts differently (or interpret the significance of the facts differently). This happens mostly, because of personal opinions, moral values, personal priorities, or politics. (Often the disagreement is over possible risks and benefits to society.)	Complex (3)
		7. Disagreements among engineers can occur because they have been influenced by companies or governments.	Simplistic (1)