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A survey of Finnish energy engineering students' knowledge and perception of hydrogen technology

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ABSTRACT

This paper presents the results of a survey of university students' knowledge and perception of hydrogen technology by interviewing 93 Finnish energy engineering students before and after a learning assignment that deals with hydrogen technology. The results suggest that both the students' knowledge and perception on hydrogen technology improve between the pre-assignment and the post-assignment surveys. The largest changes take place in their knowledge on hydrogen safety and their willingness to acquire a home hydrogen system. Correlations between the students' level of knowledge in various topics and their opinions strengthened and multiplied during the assignment. Some unexpected connections between knowledge and opinions occurred. The study argues that system-level approaches should be integrated in hydrogen energy education instead of just teaching chemical reactions or hydrogen technologies. Both radical and conventional problem settings that challenge the students to both think in a creative manner and to keep the realism should be cultivated.

Introduction

The role of hydrogen as one of the key energy carriers in the future has been acknowledged worldwide [1,2]. Universities serve as training centers and a 'knowledge link' that facilitate the integration of hydrogen technology in energy and transport systems and facilitate the transition from the present energy supply system to a new one [3]. It is estimated that 150–200,000 staff members with higher education will be needed by 2020. Here, the required number of technicians will be 50,000, and the number of sales personnel will be 30–40,000. The significance of journalists in the hydrogen transition process is recognized [3], whereas engineers are strongly involved in strategic decision making [4]. Furthermore, a significant number of personnel will be required for authorization procedures and emergency operations. Fundamentally, educated persons strongly affect the transition by communicating their knowledge and attitude. Therefore, understanding the challenges and identifying the opportunities for improving teaching and learning is necessary within the higher education of renewable and sustainable energy engineering in multi- and interdisciplinary contexts [5,6].

To integrate hydrogen in various levels of education, several projects and initiatives have been taken both in Europe and worldwide [3,7–9]. Outside specific projects and initiatives, hydrogen education has been given in short courses or training for technical staff [7], summer schools [10], and postgraduate programmes, or as a part of courses related to chemistry, physics or energy engineering [3]. Hydrogen safety, identified as one of the key instruments in lifting barriers for the transition to hydrogen economy, has been a key theme in several studies related to hydrogen education [11–14]. There

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are also some published approaches on how the hydrogen-related topics should be implemented in the classroom [15–17].

The relationship between education and the human perception of hydrogen technology has been investigated in a few studies. Education has been observed as one of the most efficient ways in having an influence on the human attitude towards new technology [18]. Typically, the positive attitude seems to go in tandem with high knowledge on the particular technology [19]. On the other hand, the high level of education may result in a conservative conception of one's knowledge about hydrogen technology, wherefore the level of education does not automatically correlate with high awareness in surveys [20].

Despite of all the aforementioned efforts of research and development, hydrogen and fuel cells are not yet an integral part of university curriculum. The results of a survey conducted by Alanne and his research team suggest that only a small fraction (6%) of the Finns equipped with engineering education identify education as a key source of information regarding fuel cells and hydrogen technology [21,22]. Although it is quite apparent that there is a significant potential to promote the acceptance and societally embed the hydrogen technology among energy engineering students through carefully selected pedagogic approaches, the literature discusses sparingly the university students' perception of hydrogen technology and how the higher education affects it. Moreover, the role of the teaching method in opinion-forming is not yet clear within the given area of application.

The present study aims at finding out the impact of educational intervention on the university students' knowledge and perception of hydrogen technology. Moreover, the objective is to investigate whether there is a correlation between the students' level of knowledge and their perception of hydrogen technology. Thus, the study fills some of the aforementioned research gaps. On the other hand, this type of a survey has not been conducted earlier among a similar target group in Finland. The research is also valuable in the sense that there is an overall lack of understanding on human perception of hydrogen technology in Finland [23]. In comparison with earlier studies with an approach of quantifying the impact of educational intervention on student learning in terms of knowledge and understanding within a particular learning period [e.g. [24]], the present research obtains an overview of the impact of education on the students' awareness and perception rather than explains the detailed impacts of learning mechanisms or processes.

Material and methods

Target course

The target course is the bachelor course 'ENE-C3001 Energy Systems', provided by Aalto University, School of Engineering. The course has been organized annually since fall 2015 and it is a part of the lower degree programme (Bachelor of Science in Technology), where it is offered with the status 'elective studies of the major subject'. The course entails five (5) ECTS credits of the total 180 ECTS, which are required to obtain the degree of B.Sc. The annual number of course participants has varied during 2015–17 within the range between 109 and 127.

The learning outcomes have been characterized by way of two categories, namely, i) learning of knowledge and ii) growing in professional identity. Following the principles of the Bloom taxonomy, the outcomes have been formulated by the statement 'having passed the course the student is capable of' [25]. Moreover, they have been classified through the identification of five levels of knowledge, namely, i) knowing, ii) understanding, iii) applying, iv) analyzing, and v) developing. The detailed formulation of the learning outcomes is shown in Table 1.

The main learning method is collaborative project working in groups of 4–5 students. Each group has to solve three (3) learning assignments that are relatively extensive and demanding group projects with partly open problem settings. The learning assignments are evaluated by the teacher with the scale 0 (failed)…5 (excellent) against the given standard of the computational results and scientific reporting. The reports are submitted through the MyCourses learning platform within a given period of time (typically 2 weeks/report). All the assignments are given to the students with some input data, literature tips and computational exercises. One (1) of the three (3) learning assignments is related to hydrogen safety and small-scale hydrogen production. Moreover, the members of each group assess the contribution of their peers (other group members). The final grade is a weighted average of the grades of the learning assignments and the peer assessment so that the learning assignment represents 70% of the final grade.

Table 1 – Learning outcomes of the course 'ENE-C3001 Energy Systems'.

Learning outcomes (knowledge)	Learning outcomes (identity)
Having passed the course the student is capable of 1. investigating whole energy systems applying the laws of thermodynamics 2. applying system thinking in describing and analyzing energy systems 3. identifying solutions to improve the energy efficiency of whole energy systems 4. determining the reduction potentials of energy consumption and environmental impact 5. justifying energy saving measures through calculations	Having passed the course the student is capable of 1. finding his/her place and working in a creative manner in an expert team, the task of which is to solve problems related to energy systems in the conditions of an open task assignment 2. communicating the terminology of energy technology within the expert team understandably and understanding 3. finding data and information using any possible data source and taking a critical attitude on the sources and the findings 4. reflecting on his/her own learning and realizing development needs on both individual and group level

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Learning assignment: 'hydrogen safety and small-scale hydrogen production'

The learning assignment is actually an educational implementation of the research work of Alanne and his research team, who in the context of the Energy Efficient Townhouse research project of the Aalto Energy Efficiency Research Programme predicted the annual rate of on-site hydrogen production for an integrated photovoltaic home hydrogen system and evaluated the annual driving distance of a fuel cell car [26]. The original research applied the dynamic whole-building simulation tool IDA-ICE and the system configuration and simulation model described by Ulleberg for advanced alkaline electrolyzers [27]. The system configuration for the original research is shown in Fig. 1.

In the learning assignment, the students are first instructed to familiarize them with the report of Nissilä & Sarsama [28] on the implementation of the EU regulations on the safety of fuel cells and hydrogen re-fueling stations and to write an essay of scientific style on the basis of what they have learned.

Second, they are asked to build an energy balance calculation sheet, by way of which they are able to determine the hourly power surplus and shortage in [Wh] from the buildings' and its systems' hourly electrical and thermal demands and the hourly PV generation. The hourly thermal demand is converted into hourly electrical demand by assuming a ground source heat pump (seasonal system COP = 2.5) as the heating system.

Third, using simplified models for the electrolyzer and compressor (derived from the work of Ulleberg [27]) they determine the hourly hydrogen production rate (in [kg/h]) on the basis of the hourly power surplus. The power requirement of the electrolyzer is calculated from

$$P = U_{cell} \cdot N_{cell} \cdot I \quad (1)$$

where U_{cell} is the cell voltage, N_{cell} is the number of cells in series and I is the current through the electrolyzer. An ideal system is modeled presuming that the electrolyzer's power requirement is equal to the power surplus. In other words, the students have to find such a current that the aforementioned condition is fulfilled. Again, the hydrogen production rate is calculated from the Faraday law

$$q_{N,H_2} = \eta_f \cdot N_{cell} \cdot \frac{I}{nF} \quad (2)$$

where $q_{N,H2}$ is molecular flow of hydrogen, η_f is Faraday efficiency, n is number of electrons per reaction (= 2) and F is Faraday constant (= 96,485 As/mol). The electrolyzer's cell area (0.25 m^2), the number of cells in series (21), the operational pressure (7 bar) and temperature (60 °C) are given as input parameters. To determine the cell voltage (U_{cell}) and the Faraday efficiency (η_f) on the basis of current density, the students are provided with a simplified calculation procedure based on the work of Ulleberg [27].

Fourth, based on the annual hydrogen production rate (in [kg/y]), the students calculate the fraction of locally produced hydrogen of the total fuel demand of the fuel cell car. Here, they are instructed to assume that all the mobility requirements of the household are fulfilled using a fuel cell car,

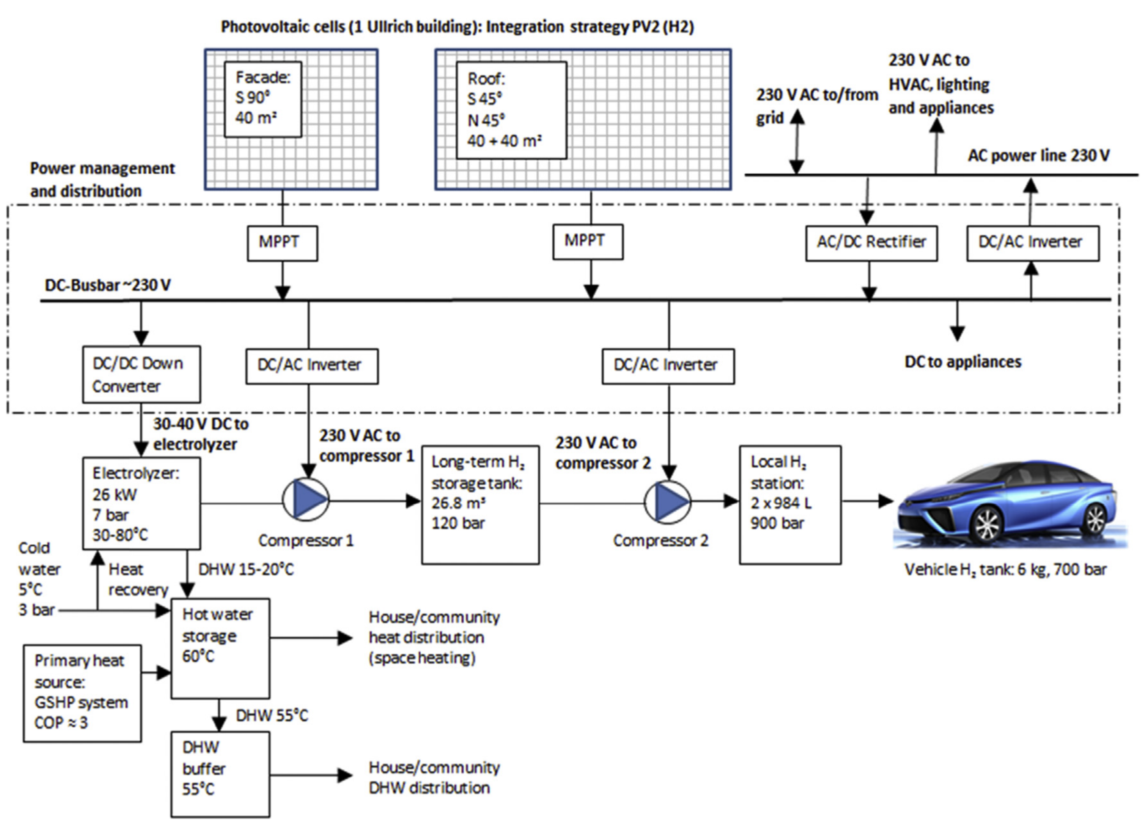

Fig. 1 – Schematic diagram of the studied home hydrogen system (based on [27]).

whereas the daily driving distance is 40 km/day and the H_2 consumption is 1.2 kg/100 km.

Finally, the students are asked to determine the on-site energy fraction (OEF), i.e. the fraction of the on-site demand covered by the on-site energy production in the cases of both with and without the home hydrogen system. In the latter case, all the surplus power is exported into the grid. The on-site energy fraction (OEF) is calculated from

$$OEF = \frac{\int_{t_1}^{t_2} MIN[G(t); L(t)]dt}{\int_{t_1}^{t_2} L(t)dt}; \quad 0 \le OEF \le 1; \tag{3}$$

where t_1 is the first hour of the year (= 1), t_2 is the last hour of the year (= 8760), $G(t)$ is the hourly power of on-site generation and $L(t)$ is the hourly power demand [29]. Hence, the integrals in the above representation describe the annual energy.

Data collection

The survey data was collected during three semesters (fall 2015, fall 2016 and fall 2017) using two questionnaires (pre-assignment and post-assignment) that were published via the Webropol online survey tool. The link to both questionnaires was delivered via the MyCourses teaching platform to those students only who were registered on the course 'ENE-C3001 Energy Systems' via the Aalto University Student Information System Oodi. The number of registered students was 352 in total. The personal data was treated in accordance with the Finnish laws and regulations and the Aalto University policies, guidelines and instructions on the use of information systems. To that end, every participant was asked a permission to use the results of the survey for pedagogic research. The final number of participants who gave a permission to use their responses in scientific research was 93 (26.4% of the total number of registered students). All the research data were stored on spreadsheets and formatted text documents that were maintained so that they were accessible by the researcher only. The use of physical paper documentation was avoided. The participation in the survey was instructed in the contact teaching situations and also through an invitation via a collective email. The students were provided with the objectives, the methods and the timetable of the survey. They were advised to answer the questions honestly and intuitively, without too much thinking. The participants were reassured that the answers do not affect the course

Table 2 – The list of background (B1…B3) and survey (S1…S2) questions and response categories.

	Question	Response categories
B1	In which year did you start your studies?	Input as number
B2	Estimate the impact of each of the following factors for your decision to participate in the course "ENE-C3001":	Likert scale: 1 (no significance)
	• I1: Interesting course content	2
	• I2: Suitable timetable	3
	• I3: Expected standard of the course	4
	• I4: Recommendation by staff	5
	• I5: Recommendation by friends	6 (extremely significant)
	• I6: Other, what?	
B3	Have your earlier studies[a] included hydrogen technology?	Yes (1) No (2)
S1	Estimate the present level of your knowledge[b] within the following areas of expertise:	Likert scale: 1 (I don't know at all)
	• K1: Chemical reactions of hydrogen	2
	• K2: Hydrogen production methods	3
	• K3: Hydrogen storage methods	4
	• K4: Fuel cells	5
	• K5: Hydrogen safety	6 (I know very much)
S2	What kind of an opinion do you have of the following statements?	Likert scale:
	• O1: I would willingly take a small-scale hydrogen production, storage and delivery system into my home.	1 (Completely disagree) 2
	• O2: In my opinion, hydrogen is a very safe option for energy storage.	3
	• O3: In my opinion, fuel cell is a very safe alternative for a combustion engine as a prime mover of a car.	4 5
	• O4: I would rather choose a fuel cell car than an ordinary electric car given that the properties and the price were the same.	6 (Completely agree)
	• O5: In my opinion, a hydrogen-based energy system is cleaner than the present energy system.	
	• O6: In my opinion, a hydrogen-based energy system is more reliable than the present energy system.	
	• O7: In my opinion, a hydrogen-based energy system is more economical than the present energy system.	

[a] In B3, the respondents were instructed so that the 'earlier studies' refer to a specific course that has dealt with fuel cells and production or delivery systems of hydrogen. Instead, chemistry courses, where the reactions of hydrogen have been treated as chemical equations or as general computational problems should be excluded.

[b] In S1, the respondents were provided with a comment that the highest options (5 and 6) refer to a professional or corresponding knowledge.

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assessment and the respondents' names will not be published in any phase of the research.

The first (pre-assignment) questionnaire was published in the beginning of the course and closed right before sharing the learning assignment 'Hydrogen safety and small-scale hydrogen production'. The second (post-assignment) questionnaire was published immediately after the learning assignment 'Hydrogen safety and small-scale hydrogen production' had been submitted by all the students via the MyCourses teaching platform.

The survey consisted of three (3) background questions and two (2) survey questions, which were designed to measure the students' awareness and their perception of the hydrogen technology on a 6-point Likert scale. Moreover, there was a room for open feedback. The survey questions were common for both pre-assignment and post-assignment surveys to enable a comparison between the answers and thus appropriate conclusions about the impact of the educational intervention. The respondents in pre- and post-assignment surveys were identified by using their student numbers. The questionnaires were published in Finnish. The questions were designed to be short and easy to answer. Appropriately chosen optional answers and background questions were intended to cover the key contents and affecting factors behind the answers. The questions were designed with an intention to define some identifiable starting level of knowledge or understanding of the topic, however, with an assumption that they can be answered not depending on whether or not the respondent have existing knowledge or experience of the subject. To dig out the students' individual perception and to encourage them to use intuition in the survey, the opinion statements were formulated in the first person, intimate words (such as the word 'home') were used and the students were encouraged to give their answers without too much thinking. In the questionnaire, single options ('radio buttons') were implemented, if possible. The questions used in the pre-course/post-assignment surveys are listed in Table 2.

The total number of students who participated in the questionnaires (fall 2015, fall 2016 and fall 2017) is specified in Fig. 2. Particularly, the diagram indicates how the 93 respondents were distributed according to their study year. Since the target course is included in B.Sc. studies, the participants were typically (75 responses, 81%) second- or third-year students, whereas the proportion of respondents representing other study years were much lower.

The responses to the questions B1 and B3 suggest that 79 of the 93 participants (85%) do not have earlier studies including specific courses on fuel cells and production or delivery systems of hydrogen. Of those 14 students who have studied the aforementioned topics, 9 represent 2nd or 3rd year-students and the others five (5) advanced (4th year or higher) students. Expectedly, the earlier knowledge seems to be slightly weighted among the advanced students, even though far-reaching conclusions cannot be made, since the percentage margin of error within this small data sample at the confidence level of 95% is up to 10% at highest.

The participants' responses to the question B2 imply that interesting course content (I1) is clearly the most significant reason for a student to participate in the target course; 80% of the respondents evaluated this statement significant or extremely significant (5 or 6 on the Likert scale). In contrast, recommendation by staff (I4) was experienced to have no significance at all by 59% of the respondents. Recommendation by friends (I5) did not attract the majority of the students to participate in the course, either.

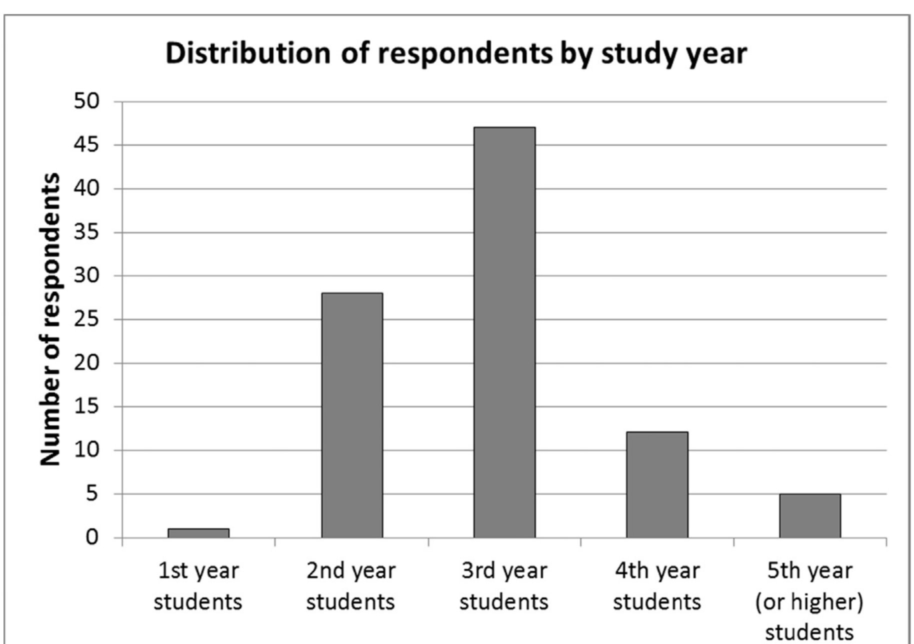

Fig. 2 – Number of respondents by study year.

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Table 3 – Summary of average, standard deviation and median of the responses to question S1.

Pre-assignment	K1	K2	K3	K4	K5
Average	2.78	2.26	2.02	2.15	2.04
Standard deviation	1.02	0.86	0.75	0.95	0.93
Median	3.00	2.00	2.00	2.00	2.00
Post-assignment	**K1**	**K2**	**K3**	**K4**	**K5**
Average	3.47	3.77	3.73	3.44	3.78
Standard deviation	1.14	1.02	1.02	1.07	1.08
Median	3.00	4.00	4.00	3.00	4.00
Difference	**K1**	**K2**	**K3**	**K4**	**K5**
Average	0.69	1.52	1.71	1.29	1.74
Standard deviation	0.12	0.16	0.27	0.11	0.15
Median	0.00	2.00	2.00	1.00	2.00

Data analysis

After closing the survey, the collected data were exported from the online survey system (Webropol) to a spreadsheet for in-depth analysis and the responses were re-organized in a single data sheet on top of each other to make the data consistent and easily readable. The responses of the participants who did not give a permission to use their responses in scientific research (14 responses in total) were removed. Hence, the final number of analyzed responses was 93.

First, a single-variable analysis was conducted. Here, it was hypothesized that both the level of knowledge and the student's perception of hydrogen technology will change due to the educational intervention. Thus, the variables were chosen so that one variable represents a particular topic of knowledge (K1…K5) or opinion statement (I1…I6, O1…O7) of each background or survey question (B2, B3, S1 and S2) and its possible range of values varies according to the variation in response categories (1…2 for question B3 and 1…6 (Likert scale) for questions B2, S1 and S2). The question B1 was converted to a more general numeric variable ‘study year’ by calculating the difference between the year the student participated in the target course and the year the studying period had first begun, whereas the response categories of the question B3 were converted into numbers (Yes = 1, No = 2). The average (mean), the standard deviation and the median were calculated for each variable on the basis of the set of responses from all the 93 participants to indicate the general level of knowledge and perception before and after the education within the data sample. Moreover, the frequencies of responses in each response category were determined and plotted for each variable to visualize the distribution of the values between response categories.

Second, a multi-variable analysis was conducted. Here, it was first hypothesized that if a participant has had earlier studies in hydrogen technology (i.e. B3 = 1), the level of knowledge will be higher by default. Therefore, the average (mean), the standard deviation and the median of each topic of knowledge within the question S1 (variables K1…K5) were calculated separately for the group of participants (cohort) who had answered ‘yes’ or ‘no’ to the question B3. Then, a comparison between pre-and post-assignment results was conducted to find out whether the hypothesis would hold and to find out how significant is the difference in starting level of knowledge in comparison with students who have no earlier studies in hydrogen technology. A justification of this problem setting is an intention to figure out whether or not the students with earlier studies would benefit from the given learning approach. In the multi-variable analysis, it was also hypothesized that there is a positive correlation between the participant's knowledge and perception of hydrogen technology. To confirm of reject that hypothesis, the Pearson correlation coefficient (r) was calculated for each combination of the topics of knowledge K1…K5 and the opinion statements O1…O7 and the significance of the correlation was tested through the two-tailed p-test.

Results and discussion

Tables 3 and 4 summarize the findings of the study in terms of calculated average, standard deviation and median for the survey questions (S1 and S2). In the second column of Table 3, the reader can perceive, for example, that the average of the students' responses to the topic K1 (‘knowledge on chemical reactions of hydrogen’) has increased from the level of 2.78 (pre-assignment) to the level of 3.47 (post-assignment), the difference being 0.69 units on the Likert scale. The standard deviations were slightly elevated in the post-assignment data, which may be an indication of that the learning assignment challenged the course participants to study the hydrogen technology from a perspective different from their earlier conception of the topic.

The variables in Table 3 were calculated separately for the participants with and without earlier studies including

Table 4 – Summary of average, standard deviation and median of the responses to question S2.

Pre-assignment	O1	O2	O3	O4	O5	O6	O7
Average	2.78	2.71	3.20	3.26	4.63	2.99	3.31
Standard deviation	1.28	1.00	1.11	1.48	1.03	0.93	1.13
Median	3.00	3.00	3.00	3.00	5.00	3.00	3.00
Post-assignment	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**
Average	4.06	3.71	3.92	3.86	5.08	3.37	3.65
Standard deviation	1.08	0.97	1.07	1.33	0.92	0.99	1.20
Median	4.00	4.00	4.00	4.00	5.00	3.00	4.00
Difference	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**
Average	1.28	1.00	0.72	0.60	0.44	0.38	0.33
Standard deviation	−0.20	−0.02	−0.04	−0.15	−0.11	0.06	0.07
Median	1.00	1.00	1.00	1.00	0.00	0.00	1.00

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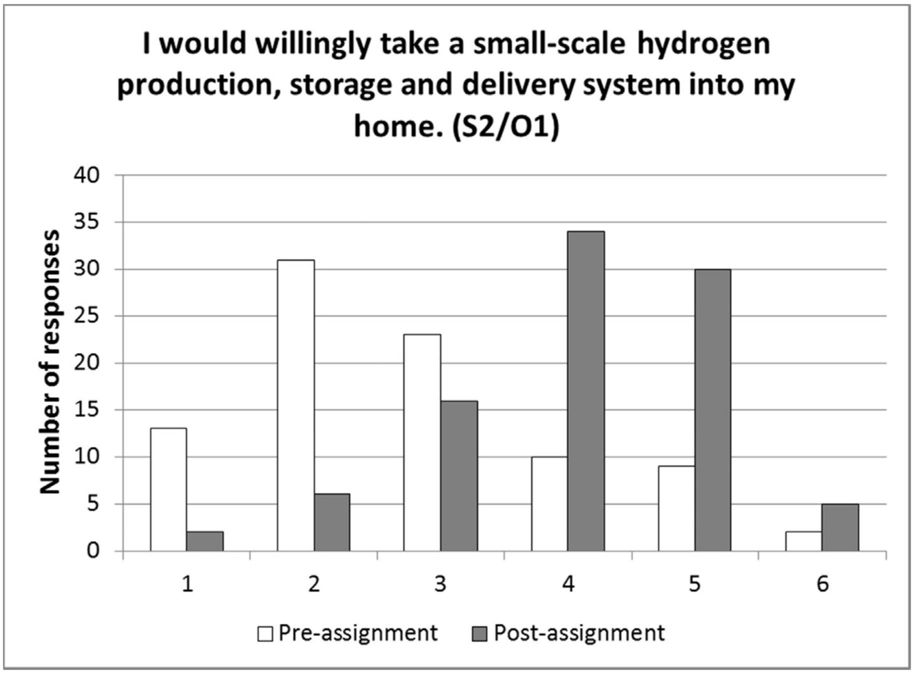

Fig. 3 – Distribution of the participants' responses to the statement S2/O1.

specific courses on fuel cells and production or delivery systems of hydrogen. The lowest pre-assignment level of knowledge for the respondents with earlier studies concerned the topics K2, K3 and K5, which may suggest that participants with earlier studies in hydrogen technology received the highest benefit from the given learning assignment within topics such as hydrogen production, storage and safety.

The data in Table 4 imply that the learning assignment particularly affected the students' willingness to acquire a home hydrogen system and on the other hand, the students' perception on the safety of hydrogen as an energy storage method. The distribution of the participants' responses to O1, as shown in Fig. 3, also supports the above inference.

Table 5 – Calculated Pearson correlation coefficients for multi-variable analysis.

Pre-assignment	K1	K2	K3	K4	K5
O1	−0.04	0.07	0.11	**0.26**	−0.06
O2	−0.10	−0.14	−0.12	0.04	−0.10
O3	0.03	0.17	0.13	**0.24**	−0.11
O4	0.10	0.14	0.09	0.20	0.08
O5	0.18	**0.26**	0.16	**0.40**	−0.10
O6	0.06	0.04	0.14	0.19	0.14
O7	0.15	0.02	0.03	0.09	**0.28**
Post-assignment	**K1**	**K2**	**K3**	**K4**	**K5**
O1	0.10	0.18	**0.22**	0.16	**0.23**
O2	0.18	**0.28**	**0.29**	**0.26**	0.14
O3	**0.22**	**0.30**	**0.26**	**0.25**	0.15
O4	0.18	**0.26**	**0.24**	0.14	0.20
O5	**0.27**	**0.28**	**0.27**	0.16	**0.26**
O6	0.15	0.07	−0.04	0.01	−0.07
O7	0.07	0.07	−0.01	0.09	−0.08

Table 5 lists the calculated Pearson correlation coefficients for the multi-variable analysis of the survey results for S1 and S2. Here, the response categories for the topics of knowledge K1...K5 have been interpreted as explaining variables, whereas those for the opinion statements O1...O7 are chosen as variables to be explained. The justification for the aforementioned approach is the hypothesis that there is a positive correlation between the participants' knowledge and their perception of hydrogen technology. Another justification is the ambition of the present study is to find support for the use of educational intervention as a means to affect the students' perceptions.

The Pearson correlation coefficient, also known as the Pearson product-moment correlation coefficient, quantifies a linear correlation between the responses to the survey questions S1 and S2. It is commonly known about testing the statistical null hypothesis, that a correlation can be interpreted as statistically significant if the probability value (p-value) is less than 5%. Applied to the data in Table 5, the two-tailed p-test results in a condition that the correlation between a topic of knowledge K1...K5 and an opinion statement O1...O7 is statistically meaningful if $r > 0.204$. (The values that fulfill the condition are written in bold in Table 5.)

In the pre-assignment analysis, the correlation between the given topics of knowledge and the given opinion statements is mainly weak or nonexistent. This result is in harmony with the findings of Tarigan et al., who suggested that the high level of awareness may result in a conservative conception of one's knowledge about hydrogen technology [20]. In practice, knowledge and opinions are two separate aspects. Therefore, one should be careful not to draw a direct conclusion that high level of knowledge results in a positive attitude towards hydrogen technology (or vice versa).

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However, in the pre-assignment data there is a perceived positive correlation between the following topic-statement couples:

- the students' knowledge on hydrogen production methods (K2) and their cleanliness of a hydrogen-based energy system in comparison with the present energy system (O5)
- the students' knowledge on fuel cells (K4) and their willingness to take a home hydrogen system (O1), their conception of the safety of hydrogen as transport fuel (O3), and the cleanliness of a hydrogen-based energy system in comparison with the present energy system (O5)
- the students' knowledge on hydrogen safety (K5) and their conception of the economical superiority of a hydrogen-based energy system in comparison with the present energy system (O7)

In the list above, the first topic-statement correlation (K2-O5) may imply that the students assume the hydrogen mainly originating from ‘clean’ energy sources even though the real production process is not exclusively ‘clean’. Correspondingly, the correlation K4-O1/O3/O5 may be partly explained by the respondents' thoughts such as that fuel cell technology is safe in both car and home, because it does not need moving parts and it is noiseless in operation. Again, the correlation between hydrogen safety and its economic superiority in comparison with the present energy system (K5-O7) may indicate that the students have in mind the economic impacts of the energy-related accidents, such as nuclear accidents or oil leaks. Given the high investment cost of the present hydrogen energy systems at present, however, the latter correlation is somewhat unexpected.

The comparison between pre-assignment and post-assignment data suggests that the number of statistically significant positive correlations between given topic of knowledge – opinion statement couples triples due to the students' participation in the learning assignment (from 5 to 15). In the post-assignment data there is a perceived positive correlation between the following topic-statement couples:

- the students' knowledge of chemical reactions of hydrogen (K1) and their conception of the safety of hydrogen as transport fuel (O3) and the cleanliness of a hydrogen-based energy system in comparison with the present energy system (O5)
- the students' knowledge of hydrogen production methods (K2) and their conception of the safety of hydrogen as energy storage method (O2), the safety of hydrogen as transport fuel (O3), the tendency to prefer hydrogen vehicles to electric vehicles (O4), and the cleanliness of a hydrogen-based energy system in comparison with the present energy system (O5)
- the students' knowledge of hydrogen storage methods (K3) and their willingness to take a home hydrogen system (O1), their conception of the safety of hydrogen as energy storage method (O2), the safety of hydrogen as transport fuel (O3), the tendency to prefer hydrogen vehicles to electric vehicles (O4), and the cleanliness of a hydrogen-based energy system in comparison with the present energy system (O5)
- the students' knowledge of fuel cells (K4) and their conception of the safety of hydrogen as energy storage method (O2) and the safety of hydrogen as transport fuel (O3)
- the students' knowledge of hydrogen safety (K5) and their willingness to take a home hydrogen system (O1) and the cleanliness of a hydrogen-based energy system in comparison with the present energy system (O5)

In the post-assignment data, new correlations are expectedly formed between the students' knowledge in hydrogen production (K2), storage methods (K3) and safety (K5) and the opinion statements related to hydrogen safety (O2, O3) and the students' willingness to acquire hydrogen technology in individual use (O1, O4). All these topics are present in the learning assignment. Correspondingly, the statement of reliability (O6) remains without correlation with the level of knowledge, since the topic is not taught in the course. For the same reason the correlation (K5-O7) dilutes in the post-assignment data.

The correlation (K1-O3) is somewhat unexpected, since in the learning assignment and the supporting material, the safety issue is coupled with legislative measures rather than chemistry. It is yet possible that the students have joined these issues on the basis of external material (e.g. Internet) or their earlier studies. The data in Table 5 also shows a weakening correlation (K4-O1) due to participation in the learning assignment, which can be explained by that the theory and practice of fuel cells in itself are not taught in the course, but the fuel cells are rather treated as components of a whole system.

Conclusions

In this paper, the results of a survey on the impact of educational intervention on university students' knowledge and perception of hydrogen technology were presented and discussed. The study hypothesized that educational intervention affects positively both the university students' knowledge and their perception of hydrogen technology. The results of the study support the hypothesis. They suggest that the average number representing the students' knowledge increases by 0.69…1.74 units on the 6-point Likert scale between the pre-assignment and the post-assignment conditions. The corresponding increase of the number representing the students' perception is 0.33…1.28. Both of the above ranges depend on the topic of knowledge and the opinion statement. The largest changes took place in the students' knowledge on hydrogen safety and their willingness to acquire a hydrogen system in their homes. The smallest changes occurred in the students' knowledge in chemical reactions of hydrogen and their perception of the reliability and economy of hydrogen systems.

The correlation between the given topics of knowledge and the given opinion statements was observed minor or even meaningless, particularly in the pre-assignment analysis. Instead, the number of statistically significant correlations tripled in the post-assignment analysis in comparison with the pre-assignment analysis, provided that the corresponding

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topics of knowledge were included in teaching. For example, a connection between the students' knowledge in hydrogen production, storage and safety and the students' willingness to acquire hydrogen technology in individual use was revealed during the teaching activity. Somewhat unexpected connections between knowledge and opinions were also found. For example, the pre-assignment data indicated that the more the student knows about hydrogen safety, the more economic he or she considers a hydrogen-based energy system in comparison with the present energy system.

The results of this study are expected to be useful in the development of learning methods and course curriculum within higher education, when the intention is to integrate hydrogen-related course contents. Particularly, the study underlines the significance of system-level approaches. Topics related to hydrogen should be treated as a part of a larger system rather than as chemical reactions or single components. The development of teaching methods calls for the implementation of both radical and conventional problem settings that challenge the students to think in both a creative and realistic manner. This could take place, for example, by offering individualized learning assignments for each working group. These could include, for example, both decentralized and centralized hydrogen production approaches based on natural gas reformation and biomass gasification and workable hydrogen delivery infrastructures for both rural areas and regions with high population density and users within short distance.

The survey covered a limited sample of students or energy technology, who participated in a single B.Sc. course. Only one teaching method was implemented and a limited number of options related to topics of knowledge and opinion statements were investigated in the survey. Therefore, limited conclusions can be drawn on the basis of this study on the impact of the educational intervention at a generic level. In the future, more research is needed to figure out the correlation between knowledge and opinions. Different teaching methods should be compared in terms of their effectiveness in influencing the students' perceptions of hydrogen technology and alleviating prejudices. Again, the change in the students' perceptions should be measured over an extended period of time and even beyond graduation and the students' progress from the university to the working life.

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