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Mutlu Cukurova, Judith Bennett & Ian Abrahams

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Students' knowledge acquisition and ability to apply knowledge into different science contexts in two different independent learning settings

Mutlu Cukurova[a], Judith Bennett[b] and Ian Abrahams[c]

[a]UCL Knowledge Lab, UCL Institute of Education, University College London, London, UK; [b]Department of Education, University of York, York, UK; [c]School of Education, University of Lincoln, Lincoln, UK

ABSTRACT

Background: Recently, there is a growing interest in independent learning approaches globally. This is, at least in part, due to an increased demand for so-called '21st century skills' and the potential of independent learning to improve student skills to better prepare them for the future.
Purpose: This paper reports a study that explored the effectiveness of two different independent learning approaches: (i) guided independent learning and (ii) unguided independent learning with independent research, in enabling students in an undergraduate Macromolecules course to acquire knowledge in one chemistry context and apply it successfully in another.
Sample: The study involved 144 chemistry students commencing their first term of undergraduate study at a northern university in England. Students completed pre- and post-intervention tests containing 10 diagnostic questions, of which 4 measured students' knowledge acquisition in one context and 6 measured their ability to apply it in another.
Design and methods: Diagnostic questions had been identified using a Delphi approach. Paired t-tests and chi-square tests were used to analyse the significance of any change in students' responses to the diagnostic questions and the number of responses evidencing misconceptions, respectively.
Results: Whilst guided independent learning settings were found to improve students' knowledge and ability to apply that knowledge in novel situations, unguided independent learning had no statistically significant effect. Unguided independent learning was also linked to a statistically significant increase in the number of student misconceptions in one of the diagnostic questions.
Conclusions: The results of this study show that guidance in independent learning activities is a key necessity for effective learning in higher education. This paper has strong relevance and high significance to tertiary STEM education, especially in the light of increased importance of teaching, such as the Teaching Excellence Framework in the UK, and shifts to more independent learning activities.

KEYWORDS
Independent learning; knowledge acquisition; ability to apply knowledge; misconceptions

CONTACT Mutlu Cukurova m.cukurova@ucl.ac.uk
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Introduction and aim

Independent learning is defined as that learning in which the learner, in conjunction with relevant others, can make the decisions necessary to meet the learner's own learning needs (Kesten 1987). Although, this definition comes from a 30-year-old source, it has been accepted and used by many recent scholars who study independent learning (Black 2007; Laurillard 2013; Seery 2012). Recently, there has been an extensive movement internationally to change teaching in higher education (HE) through a range of innovations, which promote independent learning. Independent learning has increased in importance as its role in the continuing development of an education system that promotes high quality, and lifelong learning gains recognition. Its significance may be considered as even bigger in HE as university education is the last step of formal education for the majority of the university graduates. Hence, it may be regarded as the last opportunity to develop independent learning abilities, which will possibly be the key method of learning for the rest of graduates' lives.

There is a broad acceptance (Bates and Wilson 2002; Gorman 1998; Kesten 1987) that learners develop values, attitudes, knowledge and skills needed to make responsible decisions and take appropriate actions in regard to their own learning during independent learning activities. The principles of independent learning are reflected in the design of several instructional approaches, such as problem-based learning (Barrows 1985) project-based learning (Blumenfeld et al. 1991), inquiry learning (Minner, Levy, and Century 2010), learning through information and communication technologies (Mok and Chen 2001), online learning (Heckman and Annabi 2005) and flipped classrooms (Alvarez 2011). Hence, literature reviews of independent learning (see, for instance, Meyer et al. 2008) usually rely on findings generated from a variety of teaching strategies including those cited above. Previous studies investigating those teaching approaches, showed that independent learning, when it is applied in the settings of aforementioned teaching approaches, can generate increased academic achievement (Albanese and Mitchell 1993; Davies, Dean, and Ball 2013; Vernon and Blake 1993), improve motivation and confidence (Alvarez 2011), and, reported by learners, to be a more satisfying learning experience, compared to more traditional types of teaching strategies (Belland, Ertmer, and Simons 2006; Fulton 2012).

However, there is little agreement on how independent learning activities should be used, and they are often considered to be hard to manage by teachers (Abrahams, Reiss, and Sharpe 2014). In order to shed some light on the application of independent learning approaches in their specific contexts, we investigated an independent learning approach which has features from teaching approaches mentioned earlier and involves two different independent learning activities (i) guided independent learning and (ii) unguided independent learning with independent research. It was used in a first-year undergraduate module, in the Chemistry department of a UK university. We aimed to answer two main research questions:

(1) What are the impacts of guided and unguided independent learning activities on first-year tertiary level students' knowledge acquisition and their ability to transfer this knowledge into new contexts?
(2) What are the impacts of guided and unguided independent learning activities on first-year tertiary level students' misconceptions about the content of the Macromolecules course?

Independent learning activities in instructional strategies

Promoting independent learning with variety of instruction strategies is important (Evans 1991). This requires educators building up a repertoire of strategies, which promote independent learning and gradually engage students in becoming more independent in their learning. Although, the usual approach to teaching at university has been traditional, didactic and lecture-based (Berrett 2012) which promotes the dependence of students to their teachers in their learning; for almost the last 30 years there has been an extensive movement internationally to change tertiary level teaching through innovative teaching strategies which involve independent learning activities. Even though the importance of these activities has been widely accepted, the way that they have been practiced is still a topic under discussion. One often broadly varied feature of such application of teaching approaches, which involve independent learning activities, is the amount of guidance required to be provided to the learners.

Guidance in instruction strategies

Hodson (1991, 1993) claims that independent learning activities in the sciences should only be used among students that are already familiar and happy with relevant scientific concepts, otherwise they simply become too confusing and unproductive, with no clear linkages between activities and learning. Taber (2011) argues that if students are left on their own to find solutions to problems they come across, it is very likely that those solutions are different than those scientifically accepted ones. In a similar vein, Sweller, Kirschner, and Clark (2007) suggest that students should be carefully guided towards accurate constructions, understandings and solutions during independent learning activities. However, strict guidance during independent learning activities undermines perhaps the most significant goal of independent learning activities, which is to build abilities allowing learners to be independent learners such as their ability to reason and think independently.

Possibly both researchers who argue that students should discover their own solutions independently and those who argue that students should be strictly guided towards the solutions, would accept the usefulness of the concept of scaffolding (Pea 2004) in instruction strategies. Pea describes scaffolding situations as 'those in which the learner gets assistance or support to perform a task beyond his or her own reach if pursued independently when *unassisted*' (430; emphasis in the original text). However, the problem in such arguments is that these types of descriptions are too general and open to discussions. As Clark (2009) states they do not provide enough information about 'exactly when, how, and how much support should be given and should be 'faded' without cognitively overloading unassisted learners' (160). Pea (2004) suggests in his scaffolding theory that guidance should be provided when there is 'independent evidence that the learner cannot do the task or goal unaided' (443). On the other hand, Kirschner et al. (2006) who support the strict guidance during instruction strategies argue that learners must be provided with a complete demonstration of how to perform all aspects of a task that they have not learned and automated previously, even if a learner could solve a problem with adequate mental effort, they argue that to provide a complete description of when and how is a more effective way of learning.

Previous research on guidance in instruction strategies

The effects of variations in guidance on learning have been reviewed in a combination of laboratory and field-based studies by Mayer (2004), by Kirschner, Sweller, and Clark (2006) and by Sweller, Kirschner, and Clark (2007). Most of the research on this topic concluded that guided instruction strategies are more effective approaches than allowing students time to find the solutions themselves at improving both students' knowledge acquisition and their understanding of key concepts. However, there are various individual studies frequently cited which argue the opposite. Moreover, recent interest in students' so-called twenty-first century skills development, leads to a shift in practice towards unguided teaching approaches. In this section, we reviewed some of the salient examples in this research area with the purpose of presenting the need for further research on this topic.

Fender and Crowley (2007) investigated children between ages 3 and 8 who explored a novel task solo or with parents and found that children whose parents had explained were most likely to have a conceptual understanding of concepts as opposed to procedural understanding of the task. Similarly, Klahr and Nigam (2004) found that many more students learned from instruction with strict guidance compared to leaving students to discover their solutions independently. Also, when asked to make broader, richer scientific judgements many students who learned about experimental design from guided instruction strategy performed well, while only a few of those children who discovered the method independently managed to do so. Rappolt-Schlichtmann et al. (2007) showed that students provided with guidance through modelling more complex reasoning about why objects sink or float presented more complex judgements compared to no guidance group, although their predictions about whether objects would sink or float were mostly correct from the start for both groups of students. Strand-Cary and Klahr (2008) found that at each of the three grade levels they investigated, many more students learned Control of Variables Strategy, which is often seen as a central strategy in science, in the guided condition than in the unguided condition in which students were received neither instruction about good and bad experiments nor any probe questions.

Nevertheless, the evidence about the value of guidance appears to be less clear under certain conditions. For instance, strict guidance in instruction, as Dean and Kuhn (2007) found, is neither a necessary nor sufficient condition for robust acquisition of knowledge or for maintenance of it over time. Similarly, while the guided students performed better on the definitional knowledge test; on the explanation test there was no difference between the two groups of students who were taught in guided and unguided teaching strategies (Swaak, de Jong, and van Joolingen 2004). The authors show that unguided strategies, when sufficient learning time and freedom for students in the assignments to engage in activities provided, can also result in substantial learning gains.

Student misconceptions

It has been long established that students often develop ideas that are different from those accepted by the scientific community and intended by their facilitator (Ebenezer and Fraser 2001; Taber 1999). These ideas have been given various names, such as alternative frameworks, misconceptions, misunderstandings or alternative conceptions (Gabel and Bunce 1994). Even though each description has a slight difference, such as that usually misunderstandings are claimed to be less firmly rooted and so are more amenable to change compared with alternative conceptions (Griffiths et al. 1988), in essence they all refer to students' ideas which differ from the scientifically accepted ones. As the second research question of this study is aimed at measuring the impact of the independent learning activities investigated on students' misconceptions, we reviewed the literature on students common misconceptions related to the content of the Macromolecules module and used this piece of literature while coding student answers to diagnostic questions. Examples of student misconceptions identified from the literature can be seen in the results section.

The structure of the Macromolecules course

The Macromolecules course was unique amongst students' first-year courses in being taught in independent learning. The course did not involve any lectures and students were asked to work alone to find out solutions for the given problems and tasks. In this course, students were expected to take responsibility for their own learning and to discover their own solutions.

The course had two components; the first involved guided and the second involved unguided independent learning activities. In the guided component, students were provided with a workbook based on the lecturer's previous lecture notes which had been adapted to fit in with the principles of independent learning. Students started by working through the workbook, reading the sections, finding further information via weblinks, etc., and then they attempted to answer questions provided by the lecturer which were designed to enable students' to acquire knowledge of, and understanding about, the chemical ideas in the topic. In the guided component, students were able to interact with and ask questions to their lecturers on a discussion board on the virtual learning environment (VLE). Once they had worked through the material on the guided component of the course, they were asked to answer the assessed tutorial questions on the VLE. They were allowed to use whatever resources they chose to help them to answer.

For the second, unguided, component of the course, they were asked to carry out an independent investigation into an aspect of polymer chemistry and then present their findings either, in the format of a written article or short video. The polymer chemistry contexts (i.e. climate, aviation, etc.) were suggested by the lecturer in the introductory lecture and students chose the context that piqued their curiosity among the options, suggested. They did not receive any guidance during their independent investigations from the lecturer. Students studied the course for ten weeks (one semester) and spent five weeks on guided and five weeks on unguided settings.

Methodology

This study set out to evaluate the effectiveness of two styles of independent learning on students' knowledge and their ability to apply knowledge into different contexts, hence, pre- and post-test design (Bryman 2008) is seen appropriate for data collection. To avoid sample bias, it was agreed with the course leader that they would strongly encourage the students to complete the pre- and post-tests although, for ethical reasons, tests were not compulsory. Students took the same questionnaire with 10 diagnostic questions at the beginning of their first week and 10 weeks later during the last week of the term. Figure 1

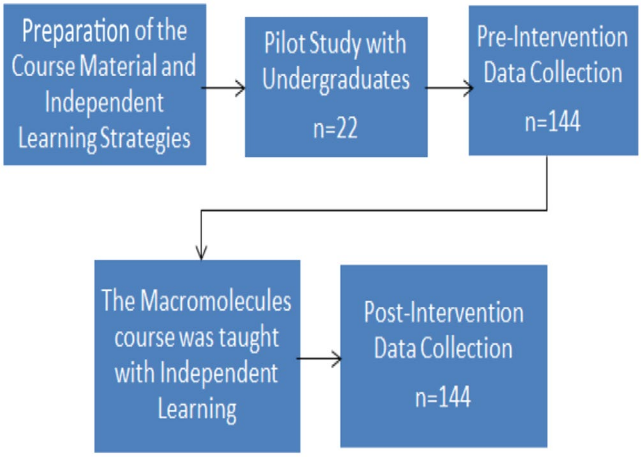

Figure 1. A general description of the empirical study.

summarises the research design. Diagnostic questions were prepared by the researchers and validated using a Delphi approach (Clayton 1997) involving three chemistry education researchers and three university lecturers, from two different UK universities. First, the module leader was asked to generate questions related to investigated chemical ideas, 10 questions each for guided and unguided parts of the module. Other lecturers and chemistry education researchers reviewed these questions whether they serve their purpose or not. In the main study, three questions from guided and seven questions from the unguided part of the study were agreed by all other lecturers and chemistry education researchers, hence they were used in the real study.

Since all of the first-year undergraduate students were taking part in this study, the questionnaires were piloted with 22 students from four other similar chemistry departments in the UK. Ten students in the pilot study studied the content of the Macromolecules module in similar unguided settings whereas the rest studied in guided settings in their departments. From the pilot study, students' feedback on the questions regarding their clarity, difficulty or typographic features were also taken into account and questions were revised before they were used in the main study.

Main study

The main study was designed specifically to probe students' knowledge acquisition and ability to apply knowledge in different science contexts. It aimed to investigate the effectiveness of the two different independent learning activities at teaching the content of Macromolecules module. The diagnostic questions that aimed to measure students' ability to apply knowledge were explorative, whilst those questions that sought to measure knowledge acquisition were descriptive in nature. Although questions from the guided and unguided components are different, they all relate to the same topic of Macromolecules in the same subject matter of Chemistry. Moreover, both approaches aim to cover the same learning outcomes in terms of content coverage. Learning outcomes were created by the module leader in collaboration with the module facilitators. The questions can be categorised into four groups according to whether they related to guided or unguided independent learning and knowledge acquisition or ability to apply knowledge to novel contexts:

Group 1: The Isomerisation and Combustion questions were devised to measure any impact of the guided independent learning on student ability to apply knowledge of geometric isomerisation and hydrogen bonding to novel contexts.

Group 2: The Kevlar's Strength question was designed to measure any impact of guided independent learning on students' knowledge acquisition on intermolecular bonds.

Group 3: The Branching, Biodegradability–Biocompatibility, Chelate (coordinate bonding) and Fashion (structure–property relationship) questions were designed to measure any impact of the unguided independent learning on student ability to apply knowledge of these chemical ideas to novel contexts.

Group 4: The Recycling, PIC and Functional Group questions were designed to measure any impact of the unguided independent learning on student knowledge acquisition on recycling and functional groups.

As can be seen, the groups contain differing numbers of questions. Three questions are about the chemical ideas studied with the guided independent learning and seven about the chemical ideas studied with unguided independent learning activities. Among them, four measured students' knowledge acquisition in one context and six measured their ability to apply it successfully in another. These numbers are the result of the Delphi study, which established which of the 20 diagnostic questions suggested by the module leader were considered as appropriate by all the experts consulted. Delphi study also aimed to ensure the comparability of questions in terms of their difficulty, clarity, type of answer they generate. The expert panel involved chemistry academics, chemistry education academics and chemistry teachers. In total, 144 first-year undergraduate chemistry students completed both the pre- and post-tests.

Qualitative analysis

Data were first coded into four categories A, B, C and D in addition to which each category was allocated a further code, either 1 or 2, representing a response with no evidence of misconception and one with evidence of misconception, respectively. Table 1 shows the final coding scheme. A chemistry education researcher and a postgraduate chemistry education student did the coding independently. Ten per cent of all answers are double coded and where there was disagreement, the researchers discussed the data and revised their codes accordingly.

Table 1. Final coding scheme.

Code	Explanation
A1	All correct with no evidence of misconception
A2	Correct with some evidence of misconception (misconception does not relate to the module content)
B1	Incomplete answer with no evidence of misconception
B2	Incomplete answer with some evidence of misconception
C1	Wrong answer no evidence of misconception
C2	Wrong answer with some evidence of misconception
D1	No response
D2	Student writes: 'Do not Know'
D3	Other comments

Reporting changed responses

First, in order to monitor general differences in students' responses, a paired sample t-test was used. Student responses were first coded according to the coding chart prepared and then enumerated in order to be transferred to the SPSS programme. In this transfer of data, A1-coded answers were accepted as the most valuable responses and C2-coded answers were accepted as the least valuable responses. The value of an answer is judged by its proximity to the expected correct answer. As every numerical representation of the 'value' of an answer, this enumeration is a hypothesis. Table 1 presents the codes in descending order. As can be seen, in our analysis, in complete answers with a misconception was considered more valuable than wrong answers with misconceptions. Using SPSS differences between students' pre- and post-intervention responses were compared using a paired sample t-test and a chi-square test both at the 0.05 level of significance.

In order to provide some insights regarding how the data were treated, we provide an example student answer below. The quote was given to the branching question by student 72, and is coded as C2 (wrong answer with some evidence of misconception).

> HDPE is more flexible, it has branches which can bond and connect in different ways more than LDPE, so it is more elastic.

LDPE is more flexible than HDPE hence the answer is not correct. Also, the answer reveals that the student thinks that more side chains mean more intermolecular bonding which is a misconception related to the content of the Macromolecules module.

Results

Table 2 presents the overall results of the diagnostic questions.

Recycling process

The question about the recycling process was designed to probe the gain in students' knowledge regarding the recycling process. Results of the paired t-test show that the students' knowledge acquisition about the recycling process was not significant $p = 0.132$ ($p < 0.05$).

Table 2. Overall results of the diagnostic questions.

The name of the question	Result of the paired sample *t*-test ($p < 0.05$)	Result of the chi-square test ($\chi^2 > 3.84$)
Recycling question	NSD $p = 0.132$	NSD $\chi^2 = 1.49$
Branching question	NSD $p = 0.283$	NSD $\chi^2 = 0.08$
PIC question	NSD $p = 0.241$	DGD
Fashion question	NSD $p = 0.209$	**SMM $\chi^2 = 5.76$**
Isomerisation question	**SPD $p = 0.008$**	NSD $\chi^2 = 0.36$
Kevlar's strength question	**SPD $p = 0.012$**	NSD $\chi^2 = 1.06$
Functional groups question	NSD $p = 0.553$	DGD
Biodegradability question	NSD $p = 0.520$	NSD $\chi^2 = 0.86$
Chelate question	NSD $p = 0.302$	DGD
Combustion reaction	**SPD $p = 0.016$**	NSD $\chi^2 = 0.06$

Notes: NSD: No significant difference, SPD: Significant positive difference, DGD: Did not generate data, SMM: Significant more misconceptions, bold values show statistically significant changes.

The number of responses which showed evidence of a misconception had decreased from 21 to 16 after the Macromolecules course. This decrease was not statistically significant, $\chi^2 = 1.49$ ($\chi^2 > 3.84$)

Some students gave responses with the same misconception after they had completed the Macromolecules course. The most common misconceptions, which were presented by 37 students, seemed to be '*every plastic is made of crude oil*' and '*we can recycle every plastic*'. Furthermore, the difference between reuse and recycling still appeared to be problematic for some students (22/144) after the Macromolecules course, as it was one of the most frequent misconceptions for students before the course.

In a comprehensive study on students' understanding of the recycling process (Kortland 1992), it was found that the depletion of raw materials was seldom, if ever, mentioned by students. In this current research study, however, this point was frequently mentioned by students. One possible reason for this difference could be the age difference between the two samples as Kortland used younger students aged 13–14 in his study.

Branching

This question probed students' ability to apply knowledge of branching to the context of HDPE and LDPE polymers' physical properties. The improvement in students' responses was not statistically significant at the $p < 0.05$ level, $p = 0.283$. The change in the number of student answers containing misconceptions was not statistically significant either, $\chi^2 = 0.08$ ($\chi^2 > 3.84$).

The result suggests that the Macromolecules course had no impact on students' ability to apply their knowledge of branching to a novel context. The most common misconception was that students thought that more branching meant more intermolecular bonding. In the post-intervention analysis, some students still continued to believe this. This finding can be related to a general intuitive rule (Tirosh and Stavy 1999) that 'the more of A (the salient quantity), the more of B (the quality in question)'. This finding suggests, as has been previously reported (Barke, Hazari, and Yitbarek 2009), that students transfer and confuse terms from the macroscopic area of matter with the sub-microscopic area of the smallest particles. In their responses to this question, the students thought that more-branched molecules can interact better with each other, just as at the macro level it would be very possible to expect that the branched parts of materials stick together more easily than the smooth parts of materials. However, this explanation does not correspond to the behaviour of polymers at the molecular level.

Plastic identification codes (PIC)

This question was designed to measure students' knowledge acquisition about the everyday life applications of polymers. Comparison of the pre- and post-intervention surveys showed a p value greater than 0.05 ($p = 0.241$), which shows that the increase in the students' knowledge acquisition about applications of PIC was not statistically significant after the Macromolecules course.

Fabrics

The Fashion and Fabrics question explored students' ability to apply knowledge of hydrogen bonding in the context of PTFE and Nylon structures. There was not, at the 0.05 level ($p = 0.209$), a statistically significant change suggesting that students' ability to apply knowledge of hydrogen bonding to different contexts was not improved during the Macromolecules course.

In terms of students' misconceptions, the post-intervention data showed that there were statistically significantly more responses with some evidence of a misconception, $\chi^2 = 5.76$, ($\chi^2 > 3.84$).

The most common problem encountered by the students in this question was that they could not transfer their thinking from the micro to the macro level or vice versa. However, the question asked the students to transfer their thinking from the atomic (micro) level (the water-repellent chemistry of those polymers) to the macro and tangible level (the waterproof and breathable features of the materials). Previous studies (Gabel 1994, 1998) have found that students struggle to comprehend and use the transfer between those levels. The reasons for this may vary, such as lack of experience with the macro type (Hodson 1990; Nelson 2002), or the existence of misconceptions about the particulate nature of matters that can impede understanding the nature of the sub-microscopic level (Harrison and Treagust 2000).

Isomerisation

This question was designed to measure students' ability to apply their knowledge of the cis- and trans-stereochemistry of polymers in the context of how polymers behave in chemical reactions. There was a significant positive change, $p = 0.08$ ($p < 0.05$) between pre- and post-intervention student responses, which indicates that some students' ability to apply knowledge of geometric isomerisation to a novel context had improved.

In terms of student misconceptions, whilst 14/144 of the responses contained misconceptions the most common of which related to trans-isomers have more steric hindrance with a further six students stating that cis- and trans-isomers could have different numbers of monomers or different numbers of double bonds, overall the change in the number of responses containing a misconception was not statistically significant, $\chi^2 = 0.36$ ($\chi^2 > 3.84$).

Kevlar

This question focused on students' knowledge acquisition of the intermolecular bonds in polymers. Comparison of the pre- and post-intervention surveys shows that the p value is smaller than 0.05 ($p = 0.01$), which suggests that student knowledge about intermolecular bonding in Kevlar has increased by a statistically significant amount.

There was no statistically significant, $\chi^2 = 1.06$ ($\chi^2 > 3.84$) change in the number of student misconceptions.

The most frequent misconception being that students associated the physical strength of Kevlar with its atom–atom interaction in the molecules (intramolecular bonds) instead of atom–atom interactions among different molecules (intermolecular bonds). In other words, some students thought that if in the molecule there is a strong bond between atoms, the molecule should be physically strong. These students associated Kevlar's physical strength with its chemical inertness. This finding is similar to previous studies (Peterson and Treagust 1989; Peterson, Treagust, and Garnett 1989; Taber 1994, 1995) that have found that students struggle to understand the relationship between intermolecular bonding and physical properties.

Functional groups

This question was designed to measure students' knowledge acquisition about functional groups. Comparison of the pre- and post-intervention surveys shows that the p value is bigger than 0.05 ($p = 0.553$), which suggests that the students' knowledge about the functional groups had not changed statistically significantly.

Biodegradability and biocompatibility question

This question investigated students' ability to apply their knowledge of biodegradability and biocompatibility to human body context. The change in the responses before and after the Macromolecules course was not statistically significant, $p = 0.52$ ($p < 0.05$). This suggests that the students' ability to apply their knowledge of biodegradability and biocompatibility to novel contexts had not changed.

In terms of students' misconceptions, there was no significant change in the post-test results, $\chi^2 = 0.86$ ($\chi^2 > 3.84$).

In the pre-test investigation, two themes of misconceptions were identified. First, biocompatibility was thought by two students as polymers' ability to bond to the human body. Second, biodegradability was confused with the dissolution of polar polymers in polar solvents. There was no change in the number of these misconceptions mentioned in the post-intervention results.

Chelate forming question

This question measured students' ability to apply knowledge of coordinate bonds to novel contexts. Comparison of the pre- and post-intervention surveys shows that the p value is greater than 0.05, ($p = 0.302$), which shows that improvement in students' ability to apply knowledge of coordinate bonding was not statistically significant.

Combustion reaction question

This question probes students' ability to apply their knowledge of combustion reactions to the context of burning plastics. Comparison of the pre- and post-intervention surveys showed that the p value is smaller than 0.05 ($p = 0.016$). These results suggest that the student ability to apply their knowledge to a novel situation has increased significantly.

Referring to the literature on students' ideas about combustion reactions, it can be seen that the number of students who are 'chemical reaction thinkers' (Watson, Prieto, and Dillon 1995, 1997) increased whilst the numbers of 'transmutation thinkers' and 'modification thinkers' (Watson, Prieto, and Dillon 1995, 1997) decreased during the Macromolecules course. The most common misconception was that four students thought that in combustion reactions products' mass is always smaller than reactants.

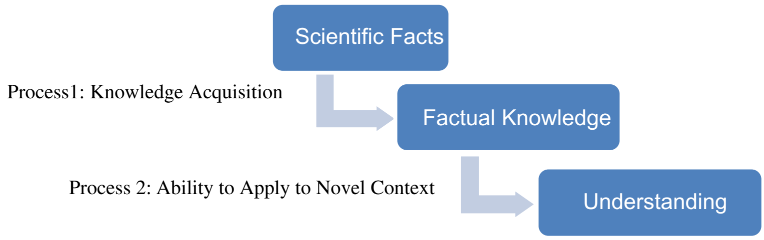

Figure 2. Learning model used in the study.

Discussion

In this current study, we have examined the effectiveness of a teaching approach, which involved two different independent learning activities relative to the lecturer's stated learning objectives and within the natural learning environment. To do this, a three-stage model of learning was used in which there were two processes (see Figure 2). Our learning model was inspired from Darmofal, Soderholm, and Brodeur (2002)'s definition of understanding as the ability to apply knowledge to a range of novel examples and circumstances. We have examined the impact of the strategy on process 1) the knowledge acquisition and on process 2) the ability to apply knowledge to a novel context.

The effectiveness of guided and unguided independent learning

Following guided independent learning, it was found that students' knowledge acquisition (process 1), as well as their ability to apply knowledge (process 2), had increased and that this increase was statistically significant. In contrast, it was found that following the unguided independent learning there had been no statistically significant change in terms of either students' knowledge acquisition (process 1) or their ability to apply knowledge (process 2).

There are two main results of this research study: first, independent learning activities applied in the Macromolecules course's guided component was effective at improving students' knowledge acquisition and their ability to apply knowledge in different contexts. Second, when students are left alone to do independent investigations, without enough support provided, their knowledge acquisition related to specific learning outcomes of the course and their ability to apply this knowledge did not change statistically significantly.

Although similar benefits of guided independent learning have been discussed in other innovative teaching approaches investigated in the literature review (Bell 2010; Bergmann, Overmyer, and Wilie 2012; Finkelstein et al. 2010; Geier et al. 2008; Kelly and Finlayson 2007; Seery 2012; Tan 2004), the vast majority of the literature that show these mentioned benefits of independent learning activities are from complex teaching approaches which makes it hard to attribute these benefits to independent learning activities themselves.

Regarding the second result, that students are not likely to become effective independent learners on their own and independent learning should be promoted (and/or taught) by the lecturers for students to become independent learners is argued by some scholars in the literature (Bates and Wilson 2002; Black 2007). Although there are a variety of reasons discussed in the literature for the failure of unguided teaching strategies (see, for instance, Tobias and Duffy (2009) such as unguided independent learning, the main reason to emerge from the current study was that the majority of the undergraduate students who undertook this course appeared to fail to make the required interaction with the key ideas of the investigated topic and focused instead on the extraneous context. Moreover, students often gather information from secondary and tertiary sources which also include information that differs from scientifically accepted ones during unguided independent activities (Cukurova and Bennett 2014).

Student misconceptions

In order for understanding to be meaningful in a scientific context, the knowledge applied in novel situations should be the correct knowledge. If the knowledge applied to novel situations is based on a misconception, the answer generated would be incorrect in a scientific context. We found that there was no statistically significant change in student responses with a misconception during guided independent learning. However, during unguided independent learning, whilst there was no statistically significant change in five out of six questions, in one case there was a statistically significant increase in the number of student responses with a misconception. These ideas containing a misconception are most likely to have developed because the students used a variety of secondary and tertiary scientific information sources – particularly from unreliable resources on the internet – during their personal investigations, and they did not have enough comprehension to separate the ideas based on a misconception from those with no sign of misconception. It is important to clarify here that there was no comparison of the types of misconceptions or how enduring they are. Our analysis was on the number of misconceptions observed in student responses.

The findings of this research study provided some evidence that student misconceptions may increase through unguided independent research. Ribeiro (1992) argues that teachers should be checking that students have understood in the way teachers intended them to, in order to eliminate possible misconceptions by students. It may be the case that the lack of interaction between teacher and students during unguided independent learning makes it hard for teachers to check whether their students acquired the understanding they intended them to. Furthermore, Ribeiro, Periera, and Maskill (1990) argued that the best way of becoming aware of the shortcomings of one's own knowledge is to rub it up against that of others. However, the unguided independent learning approach applied in the Macromolecules course appeared *not to stimulate* enough discussions among students, which would have provided opportunities for creating cognitive conflicts and the potential for exposing their shortcomings and remedy their misconceptions.

Conclusions

The findings of this study support the view that independent learning activities, when supported with guidance, can be beneficial in increasing students' knowledge of chemical ideas and their ability to apply knowledge in different chemical contexts. While findings from previous research suggest similar benefits of guided independent learning in various educational contexts (Bell 2010; Bergmann, Overmyer, and Wilie 2012; Finkelstein et al. 2010; Geier et al. 2008; Kelly and Finlayson 2007; Seery 2012; Tan 2004), these studies used complex teaching approaches, and are thus hard to attribute to the independent leaning activities alone. In contrast, this research study involved teaching approaches, which only used independent learning strategies, thus findings can plausibly be attributed to the independent learning process itself.

The independent learning approach applied in the second part of the Macromolecules course was unguided (i.e. they undertook an independent investigation into an aspect of polymer chemistry and presented their findings in the format of a written article or short video), and was not found to contribute to students' knowledge of and understanding about chemical ideas. It has been argued by many scholars (Bates and Wilson 2002; Black 2007; Bullock and Muschamp 2006; Laurillard 2013; Williams 2003) that students do not become effective independent learners on their own and independent learning should be promoted (such as by educators or technology). This study demonstrates that *unguided* independent student investigations, under the settings applied in the Macromolecules course's second part, may *even lead to an increase* in the number of students' misconceptions. The practice of leaving students to do their own investigations without any support provided should be approached with caution. As Mayer pointed out, it has been the accepted practice by some teachers to consider hands-on activities as equivalent to active learning, but active instructional methods do not always lead to active learning, and passive methods do not always lead to passive learning (Mayer 2008). Chi (2009) explained that although activities requiring hands-on active participation (such as the unguided independent learning approach applied in the Macromolecules course) from learners guarantee a level of engagement greater than passive reception of information, these activities do not guarantee that this engagement will be sufficient for them to make sense of the materials for themselves. Assuming that enabling students to interact with a specific environment will lead to learning of the desired knowledge, is very unlikely to be the case. As new knowledge is channelled by current knowledge and understanding, repetition of the learning process without appropriate guidance will very possibly lead to an increasingly idiosyncratic way of understanding the world (Taber 2011) and this idiosyncratic way of understanding is conceivably different than scientifically accepted ways.

While people may be able to construct their own understandings with little or no guidance in the context of everyday activities, such unguided independent learning activities were not found to be effective in the context of a formal undergraduate Macromolecules course. The fact that the content and context of formal education are extraordinary (Geary 2008), suggest they require more assistance to reach at scientifically accurate constructions, understandings and solutions (Sweller, Kirschner, and Clark 2007). It is important to note that the investigated learning outcomes in this research were related to *students' knowledge acquisition and understanding*. The effectiveness of the teaching approaches similar to the one investigated here, at achieving other learning outcomes including *an improvement at skills and intellectual attributes should be probed separately*.

We recognise that posing 10 questions to students in a pre- and post-test experimental design, covering eight chemical ideas of a specific Chemistry topic is a significant limitation of this study. Also, the enumeration of students' qualitative responses and potential comparability issues of the module content and the diagnostic questions for guided and unguided approaches are valid criticisms of our study. Nevertheless, we aimed to solve comparability issues in our research with a Delphi approach. Our findings suggest that the independent learning activities can benefit students' scientifically correct knowledge acquisition and understanding about chemical ideas, if they are provided with required guidance, such as monitoring student interaction via VLE and providing feedback as in the settings of the first part of Macromolecules course. However, further research studies which investigate independent learning strategies on their own is needed to be able to identify what type and amount of guidance help students improve their knowledge acquisition and understanding in specific learning contexts.

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ORCID

Mutlu Cukurova http://orcid.org/0000-0001-5843-4854
Judith Bennett http://orcid.org/0000-0002-5033-0804
Ian Abrahams http://orcid.org/0000-0001-6214-8623

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