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Who says Organic Chemistry is Difficult? Exploring Perspectives and Perceptions

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ABSTRACT
Much research has identified organic chemistry as an area of difficulty for learners. There is also much literature pertaining to the factors that contribute to learners' difficulties. This paper explores the intersections of teachers' and learners' perceptions of teaching and learning organic chemistry respectively. Understanding these nuances has implications for all involved in the teaching and learning of organic chemistry. Teachers' understanding of their learners' perspectives has a critical influence on developing meaningful learning. This paper reports the perceptions of those teaching and learning organic chemistry at high school and university level. Surveys were used to gather data from four cohorts of participants. These included high school students (n=276) and teachers (n=79) from 73 high schools as well as university students (n=121) and lecturers (n=20) from 12 different universities in Ireland. While many of the learner participants enjoyed organic chemistry and found it interesting, the majority found it difficult to learn and understand. The learners' attitudes to organic chemistry was compared with their actual level of understanding. This comparison revealed some disparity. The teachers showed a relatively accurate perception of their learners' experience of organic chemistry. While there was broad agreement between the teachers' and learners' perceptions of organic chemistry, the discrepancies are explored to inform future teaching and learning. There were different reasons why teachers and learners identified topics as easy or difficult to teach or learn respectively. This paper provides a novel contribution to existing literature by investigating teachers' and learners' perspectives. There is evidence to suggest that these participants are not aware of the multitude of complex factors impacting their experiences. The participants' views are largely-dominated by external factors in the educational contexts. While these factors are significant, it is important also that teachers and learners become more aware of the intrinsic factors. In any case, educational change is a slow process, and tangible change can only happen within individual classrooms if driven by individual teachers and learners. Many of the extrinsic factors are beyond the control of teachers and learners. However, addressing some of the intrinsic factors is within the capabilities of teachers and learners who are willing to share and develop together. The critical role of teacher's empathy and other factors are identified and addressed in this paper.
Keywords: difficulties, typical learners, organic chemistry, perceptions[1], teacher perspectives

[1] The term *perspectives* is used throughout this paper to represent the participants' own attitudes about organic chemistry. The term *perceptions* is used to represent the teachers' depiction of their learners' perspectives towards organic chemistry

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State of the literature

- Chemistry has been identified as a difficult subject by many researchers and the same topics have been identified as consistently difficult for learners in this study. This research extends current research about the difficulties with introductory level organic chemistry.
- There are many intrinsic and extrinsic factors that contribute to learners' difficulties with chemistry and organic chemistry. This research looks beyond the nature of the subject of organic chemistry itself to explore how the educational setting and context can have an effect on the teachers' and leaners' experiences of organic chemistry.
- Previous research has found that there is a mismatch between experts' and novices' perceptions of organic chemistry. This paper examines the role of empathy in this teacher-learner relationship.

Contribution of this paper to the literature

- This paper compares the learners' own perspectives and attitudes towards organic chemistry with their actual understanding of the subject's content. The discrepancies are discussed.
- Teachers' perceptions of their learners' perspective of organic chemistry are uncovered and compared with the learners' own perspectives. The teachers showed empathy for the novice learners' difficulties in learning some topics, but were unaware of the factors contributing to learners' difficulties in some topics.
- Through comparison of the teachers' and learners' own respective perspectives, discrepancies are uncovered. The rationale for increased teacher awareness of their learners' affective development is outlined to support meaningful learning in organic chemistry.

BACKGROUND

Organic Chemistry (OC) has enormous economic significance as outlined by Lopez *et al.* (2011) "*its topics are interwoven into physical, life, and applied science courses. Thus a poor foundation can have long-term detrimental effects on future STEM performance, and potentially pose a barrier to the formation of strong STEM workforce*" (p.133). As a subject, OC can cause confusion and difficulty for novice learners.

Organic Chemistry as an area of difficulty

Johnstone (2010) listed OC as one of nine areas of chemistry that were established as difficult forty years earlier in 1971. Much literature over the years (Bojczuk, 1982; Childs & Sheehan, 2009; Jimoh, 2005; Johnstone, 2006; Ratcliffe, 2002) has consistently identified OC as an area of difficulty. Almost all of the main topics in introductory OC have been identified as difficult by learners in previous research; just some of these are listed here:

- Drawing and representation of organic compounds (Johnstone, 2006; Taber, 2002)
- Isomerism (Schmidt, 1992; Taagepera & Noori, 2000)
- Properties of organic compounds (Anderson & Bodner, 2008)
- Aromaticity (Rushton, Hardy, Gwaltney, & Lewis, 2008)

- Classification of organic compounds (Domin, Al-Masum, & Mensah, 2008; Hassan, Hill, & Reid, 2004)
- Reaction types (Ferguson & Bodner, 2008)
- Reaction mechanisms (Bhattacharyya & Bodner, 2005; Ferguson & Bodner, 2008)

These studies indicate that there is a persistent problem with how OC is being taught and highlights the urgent need for change. This raises the question of whether those teaching and learning OC are aware of and understand why these difficulties are enduring.

Why Organic Chemistry is perceived as difficult?

There are three main difficulties for those learning OC (Ellis, 1994): there are no problem-solving algorithms; it requires three-dimensional thinking; and it has an extensive new vocabulary. As a subject it has a reputation for difficulty, as learners do not see its vitality and relevance in the typical high school (HS) or university (U) courses (Katz, 1996). The abstract concepts of chemistry require thinking in three domains (Johnstone, 1991), and OC is no exception to this. The three domains are the macroscopic, sub-microscopic and symbolic. The 'macroscopic' level refers to what is tangible and visible e.g. a beaker of ethanol as a clear colourless liquid. The 'sub-microscopic' level refers to what is molecular and invisible e.g. the molecules (atoms and bonds) that make up ethanol. The third dimension is 'symbolic': this refers to the chemical symbols, formulae and equations that represent the molecules and atoms etc. e.g. C_2H_5OH. While a teacher, lecturer or professional chemist may be able to move easily between these domains of thought, the combination of just any two of these dimensions, or even the comprehension of one dimension, can be demanding for a learner who has a limited or no prior knowledge and understanding of chemistry. In Irish high schools, the average age of learners beginning the senior cycle (upper high school) programme is 16 years. OC is a significant part (~20%) of the high school chemistry syllabus (DES, 1999) and examination (~25%) (SEC, 2010). Piaget (1964) predicted that cognitive development increases with age. Learners need to be at the formal stage of cognitive development in order to learn and understand core OC ideas (Ingle & Shayer, 1971). Research carried out in Ireland has found that less than 40% of U learners and less than 20% of HS learners are operating at the formal stage of cognitive development (Sheehan, 2010). OC has a high cognitive demand, hence this subject is often over-whelming for novice learners operating at the concrete stage of cognitive ability. Many of the same basic topics covered in the HS chemistry course are common to many introductory OC courses at university.

Millar (1991) categorised learner difficulties into two domains: intrinsic difficulties refer to difficulties relating to cognition and the process of learning, while extrinisc difficulties refer to difficulties associated with the subject itself, beyond the control of the learner. **Table 1** summarises some of the intrinsic and extrinsic factors contributing to learner difficulties with OC.

Table 1. Summary of factors contributing to learner difficulties in Organic Chemistry

Extrinsic Difficulties		**Intrinsic Difficulties**	
Multidimensional Nature of Chemistry	(Johnstone, 1991) (Mahaffy, 2005)	Cognitive Ability	(Piaget, 1964) (Shayer & Adey, 1981)
Complex Language	(Childs, 2006) (Childs & O' Farrell, 2003) (Selepeng & Johnstone, 2001)	Information Processing Model	(Johnstone, 1997)
Relationship with Mathematics	(Goodstein, 1983) (Coll, Ali, & Bonato, 2006)	Attitudes to Learning	(Sirhan, 2007) (Hussein, 2006)
Laboratory Work	(Letton & Johnstone, 1991) (Schroeder & Greenbowe, 2008)	Misconceptions	(McVee, Dunsmore, & Gavelek, 2005) (Taber, 2002)
Chemistry Curricula	(Bodner, 1992) (Taagepera & Noori, 2000)		

Teaching for Meaningful Learning of Organic Chemistry

Many researchers have recognised a mismatch between the enthusiasm of those teaching chemistry and the interest levels of their learners (Johnstone, 1991, 2010; Johnstone & El-Banna, 1986; Millar, 1991). There is much evidence to suggest that teaching and learning are not synonymous (Anderson & Bodner, 2008). Meaningful learning occurs when the learner can integrate the new knowledge in their existing cognitive structure. Ausubel and Novak's Assimilation Theory (Grove & Bretz, 2012) emphasises the importance of the teachers' and learners' awareness of meta-cognition on the continuum from rote memorisation towards more meaningful learning. When learners lack the cognitive ability necessary to learn and understand the topics and have low meta-cognitive awareness, they can become unaware and indifferent towards their own learning, which can lead to rote memorization and meaningless learning (Grove & Bretz, 2012). Many educational theorists (Ausubel 1963, Bloom *et al* 1956, Novak 2010) have emphasised the importance of the affective domain in underpinning meaningful learning. The affective domain includes the learners' feelings, motivation and attitudes (Krathwohl *et al* 1973). Novak's Theory of Education defines meaningful learning as the constructive integration of thinking, feeling, and acting (Novak, 2010). In this way, meaningful learning requires the integration of cognitive, affective and psychomotor learning (Galloway *et al* 2016).

Much research in mathematics (Kubiatko 2015), science (Ocak & Topal 2015) and chemistry education (as referred to earlier) have focused on identifying of learners' conceptions and experiences of learning. While less research has focused on the teachers' perceptions of their learners' experiences (Seo *et al*, 2017), there is limited specific Chemistry Educational Research (CER) investigating the intricate connexion between teachers' and learners' perspectives of OC. Some CER that has focused on the affective domain of learning has attended to the development of assessment tools (Bauer, 2005), evaluation of intervention programmes (Chase *et al*, 2016) and measuring learners' self-concept (Xu & Lewis 2011,

Reardon *et al* 2010). There has been limited research comparing teachers' and learners' perspectives of OC. Much previous literature has identified areas of difficulty for those teaching and learning OC, and the reasons why OC, as a subject is difficult to teach and learn.

RESEARCH FOCUS

This paper provides an insight into the experiences and attitudes of those teaching and learning OC. It compares the learners' own perspectives with their understanding of OC and also compares the teachers' perceptions of their learners' perspectives.

The following questions are addressed from the perspectives of both those teaching and those learning OC.

1. Is there a correlation between learners' perspectives and actual understanding of OC?
2. Do teachers have an accurate perception of their learners' perspectives of OC?
3. How do teachers' perspectives impact on the learners' experience of OC?

METHODOLOGY

This paper takes a social constructivist approach to teaching and learning OC. The close relationship between teachers' and learners' perspectives is paramount (Williams & Burden, 1997). Teachers' perspectives influence their teaching and hence the learners' experience of learning. It is important that teachers reflect on and identify their own perspectives before considering their perceptions of their learners' experiences. It is important to acknowledge that teachers' and learners' perspectives, as reported in this paper are not only experiential, but also dynamic and situated within the learning context (Bacelos and Kalaja, 2003). Although the findings from two teaching and learning settings are reported in this paper, the discussion and implications for both cohorts are comparable. For the improvement of teaching and learning, it is important that the learners' perspectives are understood (Brown, 2009).

Profile of the participants

The participants involved included those teaching and learning OC at HS and U[2]. Many students in Ireland (usually >50%) taking introductory OC courses at university have not studied HS Chemistry and therefore meet organic chemistry and its difficulties for the first time at U. For these reasons, the findings in this paper are relevant to those teaching and learning OC at both HS and U. A representative sample of 100 HSs were invited to participate. These were randomly selected from the 550 HSs teaching Chemistry in Ireland (DES, 2009). In total, 73 of the schools participated, representing 13.4% of the total number of schools offering HS chemistry in Ireland. In total, 79 teachers participated (19, 24% male and 59, 75% female). 92 (33.3%) of the HS students were male and 182 (65.9%) were female.

[2] The term 'university' is used here to represent the two types of Higher Education Institutes in Ireland- universities and institutes of technology

The U learners who participated in this study were from a total of 13 different undergraduate courses from three different institutions. HS chemistry was not a compulsory entry requirement for any of the courses. Four universities were involved in the U learner survey (n=121), and 12 were involved in the survey of the OC lecturers (n=20). The U surveys were completed during lecture time. The low participation rate at university is a result of low attendance at the lectures. 55 (45.1%) males and 62 (50.8%) females completed the U learner survey. The OC lecturer survey was distributed to 64 lecturers in total (N=64). 20 lecturers completed and returned the survey. This low response rate (31%) was partly due to the restriction of the survey. The survey was aimed specifically for lecturers teaching introductory or foundation level OC.

Data Collection and Analysis

The surveys used were validated in a previous piece of research (O' Dwyer & Childs, 2015). All surveys were coded anonymously. The learners' (HS and U) surveys had two parts. Part A focused on the learners' perspectives towards OC. The core OC topics from the HS and U Chemistry curricula were listed on a five-point Likert scale on each of the surveys for the learners to rate on a scale where 1= Really easy, 2= Easy, 3= Neutral, 4= Difficult and 5= Really Difficult. The rating scale used was adapted from previous studies investigating learners' attitudes to chemistry in the UK (Bojczuk, 1982; Ratcliffe, 2002) and in Ireland (Childs & Sheehan, 2009). Part B of the learners' survey was an Organic Chemistry Diagnostic Test (OCDT). The OCDT was tailored to accommodate the level of OC that the HS and U learners were studying. While many of the same topics were assessed in both OCDTs, the difficulty of the test was tailored to the respective curricula. The teachers' (HS teachers and U lecturers) survey focused on their own perspectives of teaching OC and also their perception of their learners' perspectives of learning OC. The same five-point Likert scale ratings were used in these surveys.

The Likert ratings and closed responses in both questionnaires were coded accordingly. The data was inputted and analysed using the Statistical Package for the Social Sciences (SPSS) Version 18.0. The results from both cohorts of learners' Likert scales were ordinal and non-parametric. The median values are included in the results of this paper. The Kruskal-Wallis Test was used to investigate if the learners' Likert rating of topics had a significant relationship with the score achieved when answering a question on the topic in the OCDTs. Before carrying out some of the significance tests, the Likert scale ratings were collapsed from 5 points to 3: Really easy and Easy were grouped as 'Easy', while difficult and really difficult were simple grouped as 'Difficult'. The Jonckheere-Terpsta Trend test was used to investigate the significance of the trends observed. The Kolmogorov-Smirnov test was used to investigate the distribution of scores in each question on both OCDTs. The distribution on both tests was non-parametric, and so the median percentage scores from each question are used in **Table 2** (below).

DISCUSSION OF FINDINGS

Figure 1 provides a framework for the findings to be discussed in this paper. The teachers' and learners' perspectives and perceptions are positioned at the core. These are encapsulated by the learners' perspectives as well as their understanding. The teachers' perspectives about teaching as well as their perceptions about learning envelope the learners' experiences. The dichotomies of teaching and learning are integral to the teaching and learning environment. The inter-face between each layer is represented with a broken line to represent the permeable nature of the teaching and learning environment. The teachers' and learners' perceptions will be discussed here with reference to relevant literature.

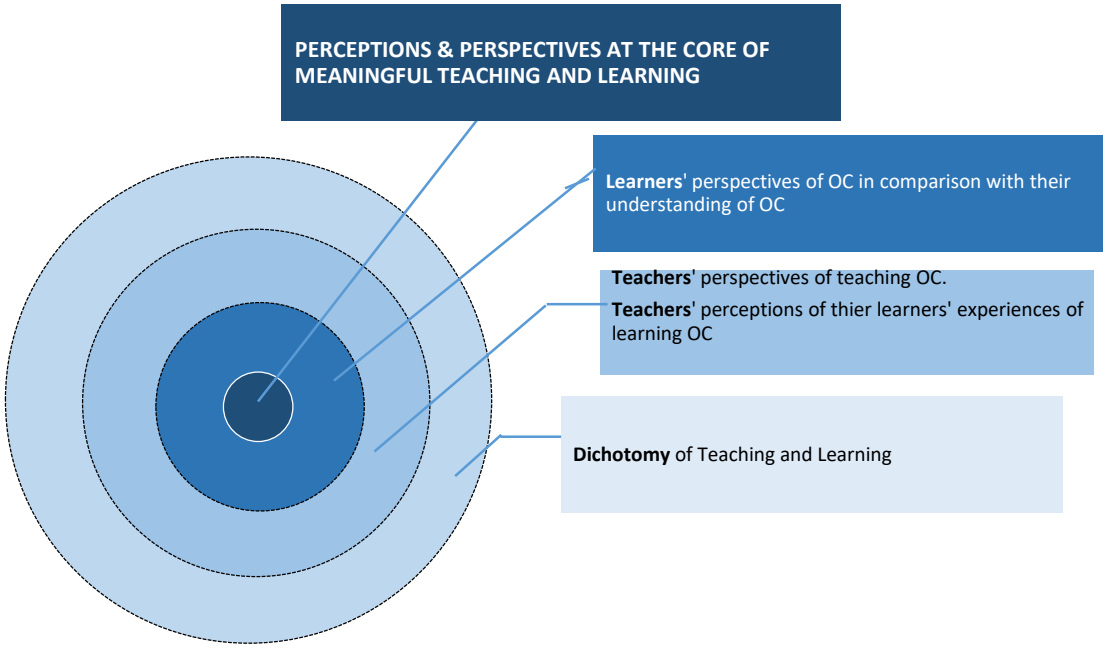

Figure 1. A layered framework representing volatility of perspectives and perceptions of the dynamic teaching and learning environment

Comparing learners' perspectives with their actual understanding of OC

HS and U learners shared their perspectives about OC, their interest in the subject as well as their experience of learning it. Almost two thirds (158, 57.9%) of the HS learners enjoyed studying OC. However, fewer (124, 45.6%) agreed that 'Organic Chemistry is one of the most interesting areas [on their HS Chemistry] course'. This may suggest that the learners had a positive attitude towards OC. However, less than one third (75, 27.5%) of the HS learners agreed with the statement 'I find Organic Chemistry easy'. 165 (59.8%) of HS learners found OC difficult to learn. Although the U learners were specifically asked to express their attitudes to studying OC at university, for over half (63, 52.1%) of the students who had studied HS OC, their perspectives may have been influenced from their HS experiences. The remainder U learners were studying it for the first time at university.

Both cohorts of learners rated a list of OC topics from their perspectives as learners. Topics listed as easiest to learn by the HS learners were drawing and nomenclature. However, drawing was the only topic that the U learners rated as easy to learn. The U learners were indifferent about nomenclature. The U learners rated reaction types, mechanisms and synthesis as difficult to learn. The HS learners also listed reaction mechanisms and synthesis as difficult topics to learn. Both cohorts of learners were indifferent in their rating of the other topics listed. The HS and U learners' perceived difficulty of reactions and synthesis is consistent with previous literature (Bhattacharyya & Bodner, 2005; Ferguson & Bodner, 2008).

To complement the perspectives and attitudes about learning OC, both cohorts of learners completed an OCDT. Two OCDTs were designed for specific use for each level of OC learners; HS and U. These OCDTs were used to assess the both cohorts' understanding of OC. The Kruskal-Wallis test found that there was a statistically significant ($p < 0.001$) relationship between how the learners rated organic chemistry and their performance in the OCDTs. Learners who rated OC as easy and/or enjoyable to learn had a higher overall test score ($\chi2(4) = 29.740$, $p= 0.000$ and $\chi2(4) = 25.203$, $p= 0.000$ respectively). In contrast, there was no significant correlation between learners' interest in the subject and their understanding ($\chi2(4) = 17.624$, $p =0.001$). Whether learners found OC interesting or not to learn did not have a significant impact on their understanding.

Table 2. Summary of the learners' performances on their respective OCDTs

UNIVERSITY (n=121)			OCDT	HIGH SCHOOL (n=276)		
$\bar{x}$ (%)	M (%)	Attempt Order	Topics	Attempt Order	M (%)	$\bar{x}$ (%)
36.4	30	1	Drawing	**1**	**80**	**77.0**
16.0	0	6	Nomenclature	2	40	44.9
31.1	20	8	Isomerism	3	**80**	**66.3**
29.3	30	4	Electrophilic attack	5	50	50.7
53.3	**60**	2	Organic species	4	50	45.6
6.28	**0**	7	Reaction Mechanism	8	**0**	**28.6**
52.7	**60**	3	Classification	6	60	56.5
50.4	50	5	Structure & Properties	7	50	55.0

Table 2 that follows shows a summary of U and HS learners' performance in the OCDTs. The mean ($\bar{x}$) and median (M) scores are included as percentages. The level of attempt for each question is also included in **Table 2**. The median test score in the HS OCDT was 52%, the median score in the U OCDT was 34%. In both tests, a score of zero was given when students did not attempt the question. It is important that **Table 2** only be used to observe a trend in

the HS and U learners' performance in their respective OCDTs, rather than a comparison of performance. While the same topics were assessed in both OCDTs, the content and level of the questions differed according to the educational level. Where a learner did not attempt a question, a score of zero was given. The U students who attempted the nomenclature question (95, 78.5%) had a median score of 20%, and the students who attempted the isomerism question (66, 54.5%) had a median score of 60%. The U students who attempted these questions did have a higher median score than the overall median suggests. However, the same was not observed for the question assessing mechanism. When the non-attempts (zero marks) were omitted from the analysis of this question, the median score of the 79 (65.3%) who attempted the question was still 0%. This suggests that unlike nomenclature and isomerism, even the students who attempted the question assessing reaction mechanism performed poorly. Reaction mechanisms was perceived as a difficult to topic to learn.

Drawing organic compounds was the first topic assessed in both OCDTs and was the most popular question on both tests. This may have been due to its position and may also imply that it is an easy topic to understand. The question assessing mechanism was the least popular question among HS learners, while the question assessing isomerism was the least popular for U learners. Drawing organic compounds and isomerism were the best answered questions in the high school OCDT while classification and recognition of organic species were the best answered questions by U learners.

These HS and U OCDT results were useful to qualify the learners' perspectives of OC. There was no significant correlation between the learners' perspectives towards the individual topics and their level of attempt of the questions assessing the topics. However, a trend was observed where the topics that had been rated as really easy or easy were attempted by higher numbers of learners. There was a significant relationship between the topics that learners were indifferent towards or described as easy to learn and their understanding of these topics. The Jonckheere-Terpstra Trend Test statistics were negative and significant for each of these topics. This indicates that the topics which were rated low on the Likert scale (1,2,3- indicating that they were not difficult to learn) were better answered in the OCDTs.

The Kruskal-Wallis H test showed that there was a statistically significant ($p < 0.01$) correlation between the learners' perspectives (Likert ratings) and understanding (OCDT performance) for the following topics: drawing, nomenclature, classification and isomerism. This suggests that the learners had an accurate perception of their understanding of the easy topics. Mechanisms were rated as difficult by both cohorts of learners, so poor performance in this topic was not surprising in both OCDTs. However, contrary to the observed trend outlined above (positive correlation between attitudes and understanding), the Kruskal-Wallis H test showed that there was no statistically significant correlation between learners' attitudes and understanding of topics listed as difficult, such as mechanisms ($\chi2(4) = 10.658.520$, $p = 0.039$). This suggests that some of the learners had a confounded perception of their understanding of this difficult topic which was consistently poorly attempted and answered.

Interestingly, nomenclature was not rated as difficult by either cohort of learners, but was poorly answered in both OCDTs. Even though nomenclature was poorly answered in the OCDTs, those who rated it as easy or very easy to learn had the best test scores for this question ($\chi 2(4) = 25.628$, $p = 0.000$). However, the overall poor performance in a topic that both cohorts identified as easy, highlights some disparity between the learners' perceptions of their own ability and their actual ability. It was expected (and observed in some cases) by the researchers that identifying a topic as easy and enjoyable would indicate competence in the same topic. However, this instance is much to the contrary. This signifies the importance of assessing learners' understanding, to validate learners' attitudes and opinions. The researchers are cognisant that how the question was presented may have been unfamiliar to the learners and may thus have affected their performance. HS and U learners can sometimes rote learn answers, but this approach was not possible in the OCDTs.

This comparison suggests that while there is some disparity in learners' perspectives about topics and their actual levels of understanding, learners may have a more accurate perspective of topics that they perceive as easy. The fact that the minority of learners who rated mechanisms as easy to learn still performed poorly in the test implies that the learners' perspectives are more accurate when the concept is within their comprehension. Discrepancies between perspectives and understanding are suggestive that these learners may be unaware of their alternative understanding of the concepts they may have developed in their strife to learn. This finding has implications for teaching OC and contributes to the plethora of research on learners' misconceptions.

Teachers' perspectives and perceptions about Organic Chemistry

In the HS teacher (n=79) and U lecturer (n=20) surveys, the participants were asked about their own attitudes to teaching OC, as well as their perception of their learners' attitudes and perspectives of the topic. The teachers' own perspectives and their perception of their learners' perspectives will now be compared and discussed.

Teachers' perspectives about teaching Organic Chemistry

HS and U teachers' perspectives and perceptions are discussed together here. Where either cohort are referred to independently, it is specified as HS teachers or U teachers. Although there are many similarities in the teachers' experiences, there are notable differences between both cohorts. In the HS setting, learners have the same teacher throughout their study of chemistry (two academic years), hence the teacher will be aware of the learners' pre-requisite knowledge base for OC. Having a longer time to develop a relationship over a two-year HS course, may better help the HS teacher to develop empathy with their students. The HS teacher has autonomy to avoid teaching the OC part (25%) of the HS chemistry syllabus (DES, 1999) as it only composes of 25% of the HS terminal examination. There is evidence that many HS learners avoid the OC section of the terminal examination (SEC, 2008). This may be suggestive of their teachers' prejudice towards OC or may be due to the learners' own choices.

In comparison to HS, where attendance is compulsory closely monitored, attendance is often the learners' own responsibility at U level. This can sometimes result in inconsistent attendance. The very often larger class size at U level and sometimes unmonitored attendance can have an impact on the lecturers' opportunity to develop a relationship and hence empathy with the U learners. Most OC lecturers at U level are subject specialist, many of whom expert researchers in the OC laboratory. This compares with HS teachers, most of whom are generalists- very often teaching a range of subjects, often including biology, physics, and mathematics in addition to chemistry. As an OC expert, it may be more difficult for U lecturers to empathise with novices' difficulties. As the U lecturer may just be teaching OC, they may not be aware of discrepancies in the U learners' prior or limited experience and study of chemistry e.g. general chemistry, biochemistry, analytical etc.

The teachers rated their perspectives of teaching OC on a five point Likert scale, where 1=strongly agree and 5= strongly disagree. The authors would like to share that the teachers' attitudes presented here are not implicit of how well topics are taught; the Likert ratings are merely indicative of the teachers' attitudes to teaching different topics. The median Likert ratings indicated that most teachers strongly agreed that OC was an interesting subject and they agreed that it was enjoyable to teach. The HS teachers were undecided about how easy OC is to teach. Of the 67 HS teachers who answered the open-ended question about teaching OC, 42 (63.0%) of these said it was easy to teach with fewer (25, 38.0%) finding OC difficult to teach. The main reasons given by teachers who found OC easy to teach, was the logical nature of the topic (22, 54.0%) and also its relevance to everyday life (16, 39.0%). The main reason given by the teachers who found it difficult to teach was the content overload (17, 68.0%). HS teachers (42, 53%) identified instrumentation as the overall most difficult topic to teach. 31 (74.0%) of these teachers, alluded to the difficulty of teaching the topic mentioning that neither they or their learners had ever used or even seen the instrumentation processes included on the HS curriculum. Vague syllabus descriptions also contributed to teaching difficulties. The second topic that most HS teachers (43, 55%) listed as most difficult to teach was organic mechanisms. The main reason given was the difficulty pre-requisite concepts needed for it to be understood (16, 37%) and the difficulty the learners have in visualising the steps of the mechanisms (13, 30%). Mechanisms are difficult to teach as they rely on the learners' accumulated accurate understanding of the functional groups and characteristics of organic species etc. Many teachers have recognised the high cognitive demand of organic mechanisms. Teachers recognised this as the stage of the course where learners' misconceptions become evident. It is notable that the reasons given by teachers here for describing a topic as easy or difficult to teach are extrinsic factors (Millar 1991, **Table 1**).

Teachers' perceptions about learning Organic Chemistry

The teachers were asked to share their perceptions of their learners' perspectives towards learning OC. The U teachers perceived that their learners find OC interesting (14, 70%) and enjoyable to learn (11, 55%) but only one felt that their students found OC easy to understand. 17 (85%) of U teachers thought that their students found OC difficult to

understand, while others felt that their learners found parts of OC easy and other parts difficult. The HS teachers agreed that their learners found OC interesting, but were unsure about how enjoyable they found it to learn. The HS teachers disagreed that learners find OC easy to learn.

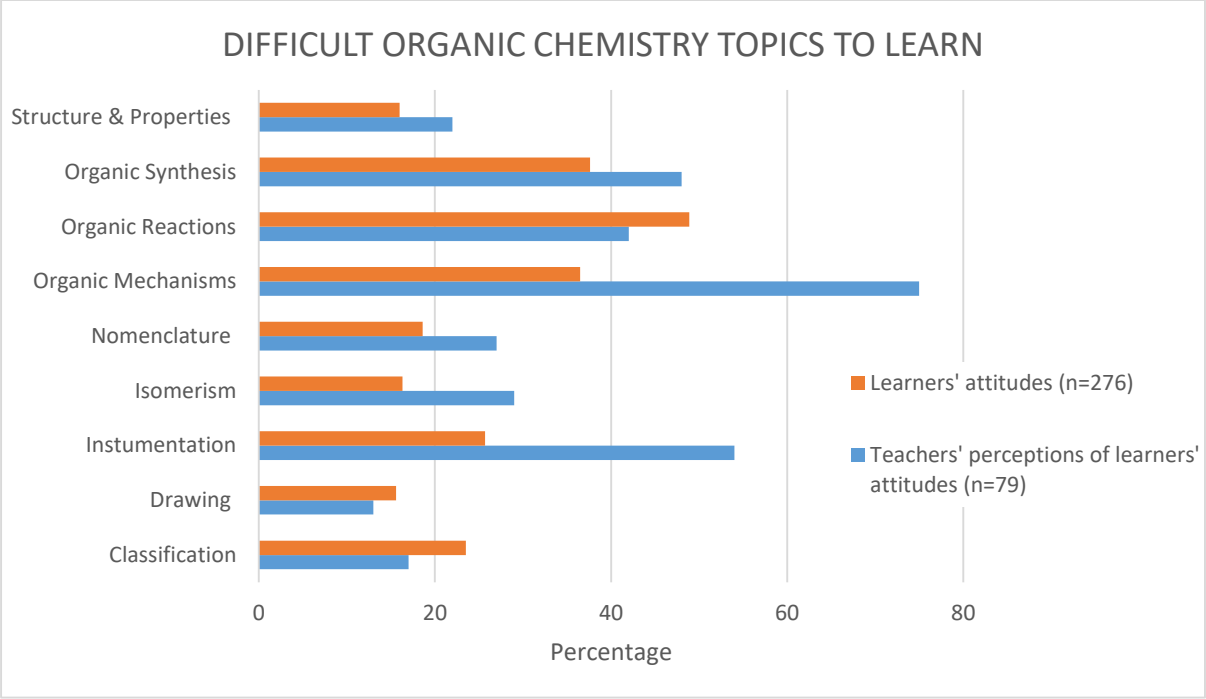

Figure 2. Comparison of HS teachers' perceptions and their learners' own identification of difficult Organic Chemistry topics to learn

Figure 2 specifically compares the HS teachers' perceptions and HS learners' own identification of the OC topics that are most difficult to learn. The topics are listed in alphabetical order. The same trend was observed when the U teachers' and learners' perspectives were compared. The U teachers listed the topics that they perceived their U learners to find most difficult. Reaction mechanisms was listed as the first or second most difficult topic to teach by 18 (90%) of the U teachers. It was also perceived as the overall most difficult topic for U learners to understand (18, 90%).

The topics listed in **Figure 2** are not surprising as previous literature has also identified these topics as key areas of difficulty in Organic Chemistry (Bhattacharyya & Bodner, 2005; Ferguson & Bodner, 2008). The HS teachers had an accurate perspective of their learners' perception and attitudes towards OC. It is notable that mechanisms was the topic that most teachers perceived their learners would have difficulty with. Given that this was rated as the most difficult topic by learners and was the least popular and worst answered question on the OCDTs, this suggests that the teachers had an accurate awareness of their learners' difficulties. It also indicates a need for further research investigating the different approaches to teaching

OC mechanisms (Freisen 2008) and teachers' perspectives about their approaches (Davidowitz & Rollnick, 2011) to topics that learners have such difficulty with.

70 (87%) of the HS teachers (n=79) answered an open-ended question, which gave a greater insight into their perceptions of their learners' experiences of OC. 53 (76%) of these teachers felt that their learners find OC difficult to learn mainly due to the overload and detail of information outlined on the curriculum. The HS curriculum and hence the teaching and learning environment can become stressful for HS teachers and learners due to the high-stakes terminal examination which determines learners' progression to university in Ireland (Smith & Banks, 2012). The difficulty of distinguishing the functional groups (10, 19%) was mentioned by some HS teachers. Reasons given by 17 (85%) U teachers who thought that their students found OC difficult to understand included the multi-dimensional nature of the subject and the different types of representations used. Other reasons given by the U teachers for learners' difficulties included poor attendance at lectures and different lecturers teaching different parts of undergraduate courses. It is important to state that such factors are not directly related to the difficulty of the subject itself but do contribute to the learners' difficulty in understanding. It is not surprising that the U and HS teachers cite the same contributing factors to rationalise why certain topics are easy or difficult to teach in their attempt to understand why learners perceive the same topics as easy or difficult to learn. The factors listed that contribute to difficulties in teaching and learning are the curriculum (content overload and vague description), the multi-dimensional and abstract nature of the subject. The logical systematic nature of OC and its relevance to everyday contexts were mentioned as aspects that facilitate the teaching and learning.

A few teachers recognised the high cognitive demand of organic reactions, mechanisms and synthesis: these topics are abstract, conceptually demanding and integrate all that the learners have learned in OC. Many of the teachers were aware that learners attempt to 'learn off' reactions and mechanisms because they have no understanding of the pre-requisite content. This is characteristic of the difficult nature of the subject and implies that some of the U and HS teachers were aware of the extrinsic difficulties that have been identified in CER (referred to in Table 1). OC has a high cognitive demand (Ingle & Shayer, 1971) and many of the HS learners are not capable of such abstract thought (Sheehan, 2010). However, the learners' cognitive ability and conceptual understanding was not mentioned by the teachers. This suggests that although the teachers were aware of some of the challenges their learners face, they were more aware of the extrinsic difficulties than the intrinsic difficulties (Millar 1991). Without clear conceptual understanding and an awareness of their own meta-cognition, learners resort to more rote memorisation and the content being learned has no meaning to the learner (Grove & Bretz, 2012).

Just 21% of the HS teachers and 30% of the U lecturers felt their learners find OC easy to learn. Reasons given included the logical nature of the topic and the systematic rules e.g. naming. These have been documented in previous CER literature as facilitating novice learners in OC (Johnstone & El-Banna, 1986; Childs, 2006). However, poor performance in the OCDTs,

suggest the novice learners were not able to recognise the systematic nature of the subject. This is illustrated in the learners' performance on the questions assessing nomenclature in the OCDTs. The International Union of Pure and Applied Chemistry (IUPAC) systemic rules are used for organic nomenclature. This logical and systematic nature of OC was mentioned by teachers in saying that OC is easy to teach and learn. However, the OCDT results imply that learners had a poor understanding of this logical nomenclature system when given unfamiliar compounds to name. This is suggestive that the learners' perspective of nomenclature as easy may be indicative of their memorisation of names of familiar compounds. The psychological sequencing and introduction of topics is critical to facilitate understanding for the novice learner. Johnstone (2000) recognised that what may be logical and simple to the chemistry teacher, may not be so for the learner. If teachers have a better understanding of their learners' cognition, they should be better able to adapt their lessons to facilitate a more holistic understanding of the subject.

The Teaching and Learning Dichotomy

From the results presented thus far, it is apparent that there is some disparity between learners' perspectives and their understanding of OC. Much evidence from the teachers' data illustrates that the teachers have a relatively reliable perception of their learners' attitudes and experiences. The value of exploring the perspectives of teachers and learners simultaneously enabled the researchers to make further deductions about the ambiguous teaching and learning settings. **Table 3** provides a summary of the teachers' and learners' respective attitudes to common OC topics. The distribution of the data from the Likert rating scales was ordinal and was found to be not normal using the Kolmogorov-Smirnov Test. The word descriptions rather than median values are used to facilitate interpretation of **Table 3**. The median values are 1=Really Easy, 2=Easy, 3= Neutral, 4= Difficult and 5= Really Difficult. It is important to note that the teachers' ratings do not simply imply that topics that are easiest to teach are the best taught topics or conversely that topics rated as difficult to teach are the most poorly taught topics. These results are only representative of the teachers' attitudes.

Table 3 consolidates the consistency of teachers' and learners' experiences of OC at HS and U level. It is worth reflecting on the apparent uniformity of perspectives in **Table 3**. The main areas identified as difficult in **Table 3** are consistent with previous research with HS teachers and learners (Bhattacharyya & Bodner, 2005; Ferguson & Bodner, 2008; Jimoh, 2005) and U teachers and learners (Childs & Sheehan, 2009). While the HS teachers and learners rated more topics as easy to teach and learn than their respective U cohorts, both groups of teachers identified drawing, nomenclature and classification as easy to teach.

The reasons that the participants gave to rationalise their perspectives of OC are of particular interest. While the teachers exhibited an accurate perception of learners' attitudes, they may not have an accurate understanding of the reasons why learners have such difficulty. As an example, U teachers expressed concern about poor attendance at lectures and complications of having multiple teachers and modules within an undergraduate course. It is

Table 3. Comparison of University and High School teachers' and learners' perspectives of teaching and learning organic chemistry topics respectively

UNIVERSITY		OC TOPICS	HIGH SCHOOL	
Teachers' attitudes to teaching (n=20)	**Learners' attitudes to learning (n=121)**		**Learners' attitudes to learning (n=276)**	**Teachers' attitudes to teaching (n=79)**
Easy	**Easy**	Drawing	**Easy**	**Easy**
Easy	Neutral	Nomenclature	**Easy**	**Easy**
Neutral	Neutral	Isomerism	Neutral	**Easy**
Difficult	**Difficult**	Mechanism	**Difficult**	**Difficult**
Easy	Neutral	Classification	Neutral	**Easy**
Neutral	Neutral	Structure & Properties	Neutral	Neutral

evident that 'local' problems are the responsibility of the U learners (e.g. to attend the lecture) and the teachers (e.g. to be aware of what is taught in other parts of the course). Similarly, the HS teachers and learners were critical of the HS chemistry curriculum: the amount, detail and volume of content. While acknowledging that these extrinsic factors (e.g. attendance and curriculum overload) contribute to the learners' difficulties in understanding the subject, it is concerning that there is little if any evidence from teachers' responses of their awareness of the intrinsic factors contributing to learners' difficulties.

Some HS teachers, many of whom teach other science subjects as well as chemistry, expressed insight into their own uncertainty in teaching mechanisms. They were reliant on the course textbook for guidance and showed some empathy for their learners' difficulties. In comparison some U teachers, as expert chemists, with high level of content knowledge lacked empathy for the novice learners' difficulties. This again emphasises the need for teachers to determine their learners' perceptions of the assessment, their workload and the teaching approaches (Trigwell & Prosser, 1991). Learners' attitudes and approaches (deep or surface learning) have been found to be related to their conceptions of learning (Prosser & Trigwell, 1999). It is of paramount importance that teachers develop an awareness of their learners' perspectives. The subject (OC) teacher needs to be aware that these attitudes may derive from prior learning experiences as well as within the learners' current experience. The OC teacher must be aware of individual learners' intrinsic needs as well as the extrinsic contextual factors alluded to by the teachers in this study.

Teaching and learning is an intricate practice with many intrinsic and extrinsic factors influencing classroom experiences and relationships. Meaningful learning is dependent on three conditions: i) the learner must have some relevant prior knowledge to which the new information can be related, ii) the material to be learned must contain important concepts and propositions relatable to existing knowledge, and iii) the learner must consciously choose to non-arbitrarily incorporate this meaningful material into their existing knowledge (Ausubel, 1963). The teachers' perspectives and how the material is presented has considerable impact on the learners' experiences and development of understanding. While it is true that much of

the findings shared in this paper demonstrate teachers' empathy of their learners' difficulties, much of the findings highlight the influence that teachers' attitudes can have on learners' experiences and perspectives. While teachers' positive attitudes, interest and enjoyment of OC may stimulate learners' respective experiences, conversely their own diffident perspectives of many topics may have substantial impact on their learners' perspectives and learning of many of the topics. The insights gained about teachers' perspectives in this study imply that teachers' perceptions and how these are communicated with the learners can have significant effects on learning. It is important that teachers are cognisant of their influence on their learners in generating preconceptions about difficult topics. The authors are cautious that although a level of teacher empathy is important in reassuring the learner, some findings may imply that teachers' own perspectives of the difficulty of topics may impact on the effectiveness of the teaching and learning of these topics and in turn their learners' experiences and perspectives.

IMPLICATIONS & CONCLUSIONS

While the learners showed an accurate appraisal of the OC topics that they find difficult, it was apparent that many learners had a false perception of some topics; rating them as easy, but yet performing poorly when understanding was assessed. The teachers' and learners' perspectives of OC presented in this paper clearly represent a complex interplay of numerous factors, both systematic and pedagogical. Rather than attempting to determine best practices in teaching and learning OC, this paper provides insight into the myriad of perspectives and perceptions within the OC learning environment, highlighting many of the factors that influence the stakeholders. The authors believe that both teachers and learners could benefit from this increased awareness.

Limitations of this research

This paper exploited the value of teachers' and learners' perspectives and the dichotomy of both in some cases. The authors would like to state that any conclusions drawn from the findings shared and discussed here are exploratory, given the difficult nature of interpreting purely quantitative data. Inclusion of qualitative interviews with OC teachers and focus groups with learners would substantiate the findings of this paper by elucidating many of the quantitative responses. This paper did not report on teachers' methodologies, but instead the teachers and learners' perspectives of topics and how they are taught and learned. Classroom observations could consolidate or challenge many of the perspectives shared in this paper.

Policy

Much research has documented the overload of the current Irish HS curriculum and examination system (Smith & Banks 2012), which is a common feature of many international HS systems. Although this same problem does not exist at university level, similar challenges exist. Many university undergraduate programmes are fragmented as different lecturers design and teach individual modules- too often with limited insight into the learning in other modules within the programme (Fraser & Bosanquet, 2007).

The HS chemistry curriculum is currently under review in Ireland (National Council for Curriculum and Assessment (NCCA) 2012). It is of paramount importance that the curriculum review is adequately coupled with the necessary professional development for in-service teachers. Given the dominance of extrinsic factors alluded to in the findings of this paper, it is evidence that curriculum developers at HS level and programme developers at U level need to become more aware of learners' meta-cognitive development and teachers' understanding of the intrinsic factors that contribute to learners' difficulties with many topics. One may argue that U teachers have more freedom to negotiate their curriculum development with fellow academics (Brew & Barrie 1999) than their HS counterparts. However, insights from the teachers and learners shared in this paper highlight the need for teachers' increased awareness of how their learners learn and how to link their learning of OC to other learning. Given the subject content expertise of many U teachers, it may also be necessary to accredit and acknowledge U teachers' professional development in teaching and learning (National Forum for the Advancement of Teaching and Learning, 2016).

Practitioners

Just as learners' experiences are individual, so too are teachers' experiences of teaching. Given the policy recommendations outlined above, there are additional implications for practitioners. Teachers' perspectives of their local context, their methodologies and pedagogies vary between individuals, even within the same educational setting (HS or U). While there has been much research on learners' perceptions in a variety of contexts, teachers need to become more aware of their own perspectives and the influence these have on their classroom teaching and on their learners' experience. Developing an awareness of their own personal perspectives may accustom teachers to the affective domain of learning. Too often, media and anecdotal perspectives from outside the learning space can influence teachers' perceptions of their practice. Teachers need to be aware of how their own perspectives of a subject may have positive and / or negative implications for their learners' experience and development.

Evidence from research in Mathematics education has found that teaching and learning can be enhanced in a supported environment where teachers have the opportunity to recognise intricate features of their learners' meta-cognition (Llinares *et al.,* 2016). This is not to suggest that teachers should teach using only strategies and techniques that learners approve of, but that they should try to bridge the gap between their perspectives of effective teaching and those of their learners.

The teachers' attitudes about teaching OC were similar to previous research carried out in UK (Bojczuk, 1982; Ratcliffe, 2002) and in Ireland (Sheehan, 2010). This indicates that the same challenges in teaching and learning OC will persist from HS to U level if the issues are not addressed. The findings from the HS and U participants exhibited many commonalities. This suggests that those learning OC at university (often with no experience of HS chemistry) experience many of the same difficulties as those learning OC for the first time in high school.

Since many of the same difficulties are experienced by both cohorts of learners, the same strategies may be used to address the difficulties in both levels of education. There is evidence that many of the difficulties and misconceptions developed in the study of HS OC are carried through to U level. It is important that HS and U teachers consider the intrinsic factors; the abstract nature of the subject as well as the cognitive abilities of their learners to begin with to understand why topics often perceived as 'easy' by the experts can cause much difficulty for a novice learner.

The differences between the HS and U teaching environments were discussed earlier with reference to how the contrasting factors may impact on the teaching and learning in both settings. U teachers, as subject specialists, are often most confident in their subject content knowledge while HS teachers as general science teachers, may have more confidence in their pedagogical content knowledge. It is evident that there is scope for both cohorts to reflect and self-assess their teaching strengths and shortcomings. The professional development bodies such as National Forum for the Advancement of Teaching and Learning (2016) and the Teaching Council of Ireland (in Ireland) need to accommodate for teachers' learning needs in their strife to improve their learners' experiences.

Research

The teachers identified topics as difficult to teach as they recognise that these are the topics that their learners have most difficulty understanding. These same topics were negatively perceived and poorly understood by the learners. This finding may suggest that if better teaching strategies or approaches were available for and used by these teachers, these topics may become easier to teach, and in turn easier for the learners to understand if they are better taught. The authors acknowledge there are many implicating factors underwriting this tentative connexion, so therefore suggest that further research into how teachers' perspectives influence their methodological approaches and hence their learners' experiences.

The findings have highlighted a number of extrinsic factors contributing to teachers' and learners' difficulties with OC. The constraint of a prescribed and over-loaded curriculum (DES 1999) in addition to the focus on preparation for terminal examination (Smith & Banks 2012) can restrict teachers' autonomy and time available to ascertain learners' meaningful learning. Similarly, U teachers are often focused on teaching one module without insight into the broader undergraduate programme(s) of study. Although the participants in this research were from over 80 individual classroom settings, the authors believe that the most practical impact of future research may not be at a macro level but instead at the individual classroom level. Each learning environment (although within the same education context), is unique. There is a need for teachers to become researchers who desire to understand their own and their learners' perspectives- both affectively, as well as cognitively.

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